AD-A031 912 ARMY AVIATION TEST BOARD FORT RUCKER ALA F/G 17/7

MILITARY POTENTIAL TEST (COMPARATIVE EVALUATION) OF DOPPLER NAV--ETC(U)

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1 OF 3

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US ARMY TEST & EVALUATION COMMAND

REPORT OF TEST

USATECOM PROJECT NO. 4-3-3600-( )-G

MILITARY POTENTIAL TEST (COMPARATIVE EVALUATION)

OF DOPPLER NAVIGATION SYSTEMS

~~FOR OFFICIAL USE ONLY~~

JC Malloy
USAADTA (PROV)
13 Apr 76
AR 340-16

US ARMY

AVIATION TEST BOARD

FORT RUCKER, ALABAMA

UNITED STATES ARMY AVIATION TEST BOARD
Fort Rucker, Alabama 36362

STEBG-TD

14 FEB 1964

SUBJECT: Revision to Report of Test, USATECOM Project Number 4-3-3600-( )-G, "Military Potential Test (Comparative Evaluation) of Doppler Navigation Systems"

TO: Commanding General
US Army Electronics Command
ATTN: AMSEL-AV-E
Fort Monmouth, New Jersey

1. Reference is made to:

a. Report of Test, USATECOM Project Number 4-3-3600-( )-G, "Military Potential Test (Comparative Evaluation) of Doppler Navigation Systems," US Army Aviation Test Board, 6 January 1964.

b. Conference at Headquarters, US Army Electronics Command, Fort Monmouth, New Jersey, 12 February 1964.

2. Revisions to reference a were agreed upon by representatives from US Army Materiel Command, US Army Electronics Command, and US Army Test and Evaluation Command (reference b). These revisions have been made and are attached as inclosures 1, 2, and 3.

3. Request the following action be taken:

a. Remove and destroy letter of transmittal dated 6 January 1964 and insert letter of transmittal dated 14 February 1964 (inclosure 1).

b. Insert pages v and vi (inclosure 2) and make necessary pen-and-ink corrections to the report.

De Malloy
USAADTA (PROV)
13 Apr 76
AR 340-16

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STEBG-TD
SUBJECT: Revision to Report of Test, USATECOM Project Number 4-3-3600-( )-G, "Military Potential Test (Comparative Evaluation) of Doppler Navigation Systems"

14 FEB 1964

c. Remove and destroy pages I-7 and I-8 of the report and insert revised pages I-7, I-8, and I-9 (inclosure 3).

3 Incl
as

A. J. RANKIN
Colonel, Armor
President

Copies furnished:
- CG, USATECOM (2)
- CO, USAEPG (1)
- CO, USAATA (1)

UNITED STATES ARMY AVIATION TEST BOARD
Fort Rucker, Alabama

REPORT OF TEST

USATECOM PROJECT NO. 4-3-3600-( )-G

MILITARY POTENTIAL TEST (COMPARATIVE EVALUATION)

OF DOPPLER NAVIGATION SYSTEMS

ERRATA

Make pen and ink corrections as indicated below:

1. Title page.
ADD: REVISED 14 FEBRUARY 1964.

2. Page I-6, paragraph 5.
CHANGE to read: "...engineering test. (Table 5 of appendix A provides sensor and computer accuracy and does not represent total navigation system accuracy.) The relative order..."

3. Page I-6, paragraph 6.
ADD: The reliability was determined by evaluating the number and type of failures and the maintenance performed. Due to the limited number of test equipments and the available test time, no Mean Time Between Failure (MTBF) figure was derived.

4. Page II-20, paragraph i(2)(a).
ADD: (Doppler system B required calibration and adjustment to permit operation below its design limits of 40' and this was accomplished at the expense of required high altitude operation.)

5. Page II-24, caption for figure 32.
CHANGE to read: "...flight course, clockwise."

6. Page II-25, paragraph 1, line 3.
CHANGE to read: "appendix A). No attempt..."

7. Page II-26, caption for figure 33.
CHANGE to read: "...flight course, counter-clockwise."

Inclosure 2

8. Page II-29, paragraph 8b.
ADD: There was no significant difference observed on the ease of maintenance between the systems tested.

9. Page II-40.
ADD:

Shortcoming	Recommended Corrective Action	Remarks
(9) Doppler derived wind memory circuit malfunctioned intermittently.	Correct wind memory circuit malfunction.	Cause of malfunction was not determined prior to completion of test and may be an installation or a maintenance problem.

10. Page III-5, paragraph 3c.
DELETE: "and was the lightest in weight and least expensive of all tested systems."

11. Page III-36, caption for figure 35.
CHANGE: "valves" to read "values".

12. Page III-37, caption for figure 36.
CHANGE: "valves" to read "values".

13. Page III-142, caption for figure 38.
CHANGE: "APV" to read "APU".

natural cosine functions, either by use of a slide rule or from published tables. This training was accomplished in approximately 12 hours.

b. First- and second-echelon maintenance by military personnel could be accomplished by an Aviation Electronic Equipment Mechanic, MOS 284.1, with additional training. This training was estimated to require at least 16 hours of classroom instruction and 22 hours of on-the-job training. Third-echelon or higher maintenance would require extensive training. These skill levels and training requirements were determined from actual maintenance performed by the three manufacturers on their equipment during the test. The maintenance required at Fort Rucker, Alabama, is presented in part II and the maintenance required at Fort Huachuca, Arizona, is discussed in appendix A, part III.

10. The US Army Aviation Human Research Unit at Fort Rucker, Alabama, stated: (see appendix N, part III).

"a. The ManufacturerC doppler navigation system appears to be the best designed of the three systems from a human factors standpoint. All three systems have a number of human factors discrepancies which should be corrected before a system is adopted for use in Army aviation.

"b. No system provides satisfactory methods or capability for manual correction of position counters while the aircraft is in flight on low altitude tactical missions. For this reason all three systems are considered unacceptable from the human factors standpoint. All three systems will reduce the routine data processing demands made on the pilot, but significant and needed additional improvement in tactical performance could be obtained by a careful redesign of the systems with particular attention given to the functional requirements of Army aviation."

11. The Federal Aviation Agency (FAA) at this date does not recognize Doppler navigation systems as being suitable for Federal Airway use when employed as the primary navigation means. However, the FAA, subsequent to the initiation and prior to the completion of the current FAA Doppler Test project, published an Advisory Circular (reference 13), effective 9 July 1963, outlining the policy relative

to the installation and use of self-contained navigational aids in air-carrier operations. The following quotes indicate that the use of Doppler airborne navigation systems is not entirely ruled out as a future primary navigation aid:

"a. Cockpit navigation over international routes previously requiring a navigator may be approved using self-contained navigation in conjunction with ground-based aids.

"b. Use of self-contained navigational aids within the National Airspace Utilization System shall not be approved by Regional Offices prior to review by Washington Federal Aviation Agency Headquarters."

H. Conclusions:

1. The Doppler navigation system of Manufacturer C is the most suitable of the systems tested for Army use in both fixed- and rotary-wing aircraft.

2. Provided deficiencies are corrected, the Doppler navigation system of Manufacturer A should be suitable for Army use in both fixed- and rotary-wing aircraft.

3. The pictorial navigation display board furnished with Manufacturer C's system represents the most advanced state-of-the-art, and should be considered the most suitable for Army use.

I. Recommendations. It is recommended that:

1. The Doppler navigation system of Manufacturer C be type classified for Army use in both fixed- and rotary-wing aircraft.

2. In the event the Doppler navigation system of Manufacturer A is selected, the deficiencies must be corrected, and the modified navigation system be check-tested prior to type classification.

3. The shortcomings on the system selected as listed in paragraph C, part II, and appendix L, part III, and the discrepancies enumerated in appendix N, part III, be corrected as technically and economically feasible.

4. An improved compass system and associated calibration equipment for field use, compatible with the Doppler system, be provided for Army use.

A. J. RANKIN
Colonel, Armor
President

US ARMY AVIATION TEST BOARD
Fort Rucker, Alabama

USAAVNTBD Project Officer:
James F. Vaughn
Major, Signal Corps

USAEPG Project Officer:
William P. Hemming, III
DAC

9 Final rept.

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REPORT OF TEST

USATECOM PROJECT NO. 4-3-3600-( )-G

6 MILITARY POTENTIAL TEST (COMPARATIVE EVALUATION) OF DOPPLER NAVIGATION SYSTEMS.

(This report comprises the reports of tests of USATECOM Project Numbers 4-3-3600-05-G, 4-3-3600-06-G, and 4-3-3600-07-G.)

FOR INFORMATION ONLY
ACTION BY HIGHER HEAD-QUARTERS PENDING

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UNITED STATES ARMY AVIATION TEST BOARD
Fort Rucker, Alabama

REPORT OF TEST

USATECOM PROJECT NO. 4-3-3600-( )-G

MILITARY POTENTIAL TEST (COMPARATIVE EVALUATION)

OF DOPPLER NAVIGATION SYSTEMS

Table of Contents

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UNITED STATES ARMY AVIATION TEST BOARD
Fort Rucker, Alabama

REPORT OF TEST

USATECOM PROJECT NO. 4-3-3600-( )-G

MILITARY POTENTIAL TEST (COMPARATIVE EVALUATION) OF DOPPLER NAVIGATION SYSTEMS

CODE SHEET

This code sheet will be removed from the report when loaned or otherwise distributed outside the Department of Defense.

Code	Name of Manufacturer
Manufacturer A	Ryan Electronics Division of Ryan Aeronautical Company
Manufacturer B	General Precision Laboratories Division of General Precision, Inc.
Manufacturer C	Canadian Marconi Company
Manufacturer D	Electronics Division, ACF (Manufacturer of a pictorial display)

Code	Title of Equipment
Doppler A	RYANAV IV Doppler Navigation System
A (FW)	Fixed-Wing System-Installed in OV-1( )
A (RW)	Rotary-Wing System-Installed in UH-19D
Doppler B	General Precision Laboratories Doppler Navigation System
	Fixed-Wing System-Installed in OV-1( )
Doppler C	Canadian Marconi Company Doppler Navigation System
C (FW)	Fixed-Wing System-Installed in OV-1( )
C (RW)	Rotary-Wing System-Installed in UH-19D

[redacted]

UNITED STATES ARMY AVIATION TEST BOARD
Fort Rucker, Alabama

REPORT OF TEST

USATECOM PROJECT NO. 4-3-3600-( )-G

MILITARY POTENTIAL TEST (COMPARATIVE EVALUATION)

OF DOPPLER NAVIGATION SYSTEMS

PART I - GENERAL

A. References. A list of references is contained in appendix O, part III.

B. Authority.

1. Directive. Message, AMSTE-BG TT8398, US Army Test and Evaluation Command, 17 May 1963.

The was

2. Purpose. To develop test data for use as a basis for recommending the most suitable Doppler navigation system(s) for Army use.

C. Background.

1. Within the Combat Development Objectives Guide (CDOG) (reference 14), the US Army has established two self-contained airborne navigation requirements. One requirement cites a specific type of self-contained navigator (paragraph 533c(5)). The second requirement specified a need for a Self-Contained Lightweight Navigator (paragraph 533c(6)). Both requirements are classified CONFIDENTIAL.

2. A Doppler navigation system (AN/APN-118) was under development for Army use but failed to meet Army requirements and the program was terminated prior to completion.

3. As a result of the joint US Army Electronics Command (USAECOM) - US Army Test and Evaluation Command (USATECOM) Electronic Materiel Test and Evaluation Program conference at Fort Monmouth, New Jersey, 10-11 April 1963, it was proposed that an

[redacted]

evaluation of commercial "off-the-shelf" Doppler navigation systems be conducted. US Army Materiel Command (USAMC) concurred in the proposed evaluation and directed an expedited program to furnish an overall comparative evaluation. The US Army Electronic Proving Ground (USAEPG) was designated as a Task Agency to perform the engineering portion of the test and the US Army Aviation Test Board (USAAVNTBD) was designated Executive Test Agency to coordinate and forward a final report to USAECOM not later than 7 January 1964. USAECOM was to recommend to USAMC the most promising system.

4. Industry was solicited to determine the available "off-the-shelf" systems having a military potential. Five manufacturers submitted proposals to the Army for review to determine the adequacy of the proposals for further consideration.

5. Three manufacturers' proposals providing a total of five systems for test were accepted on 24 June 1963. Two manufacturers (A and C) each provided a system for both fixed- and rotary-wing aircraft. Manufacturer B provided a system for fixed-wing only.

6. The expected delivery date was 2 September 1963. Actual delivery dates were:

Manufacturer	Doppler	Date Received	Aircraft in Which Installed
A	A (FW)	2 Sep 63	OV-1( )
B	B (FW)	4 Sep 63	OV-1( )
C	C (FW)	19 Sep 63	OV-1( )
A	A (RW)	13 Sep 63	UH-19D
C	C (RW)	19 Oct 63	UH-19D

7. Flight safety certification for each system was recommended by the US Army Aviation Test Agency (USAATA) (reference 26) and approved by USATECOM (references 18 and 19).

D. Description of Materiel. Each of the systems tested employed a Doppler radar sensor which measured the velocity of the aircraft by use of the Doppler principle. Microwave energy was radiated to the ground in multiple beams and was reflected back to the aircraft. By detecting the amount of Doppler shift of the reflected beams, the velocity vectors of the aircraft were determined and

fed into a computer together with the heading from the aircraft compass system. The computer outputs were then used to drive the navigation displays for the pilot. Each system employed different techniques in obtaining the Doppler shift, and each system used a different presentation for the navigational information being furnished the pilot.

1. Manufacturer A Dopplers A(FW) and A(RW). These Dopplers employed a three-beam radar sensor for use in both fixed- and rotary-wing aircraft. The sensor emitted a continuous wave at a frequency of 13,300 megacycles. The system weighed 90 pounds 14 ounces (paragraph B1a, part II).

2. Manufacturer B Doppler B (FW). This Doppler employed a four-beam radar sensor and was designed for fixed-wing application only. The sensor emitted a pulsed continuous wave at a frequency of 13,325 megacycles. The system weighed 108 pounds 13 ounces (paragraph B1b, part II).

3. Manufacturer C Dopplers C (FW) and C (RW). These Dopplers employed a four-beam radar sensor for use in both fixed- and rotary-wing aircraft. The sensor emitted a frequency-modulated continuous wave at a frequency of 13,325 megacycles. The system weighed 91 pounds 2 ounces (paragraph B1c, part II).

E. Test Objectives.

1. To determine which system(s) most nearly meet the requirements stated in paragraph 533c(5) of the CDOG. No military characteristics were written for this paragraph. (See appendix Q, part III).

2. To determine which system(s) most nearly meet the requirements stated in the military characteristics developed for paragraph 533c(6) of the CDOG. (See appendix L, part III.)

3. To determine which system(s) most nearly meet the US Army Electronics Research and Development Laboratories (USAELRDL) Technical Requirement technical specifications (reference 5).

4. To obtain operational and technical data on the performance of each system when operating throughout the flight regime of the aircraft in which installed.

5. To ascertain the suitability of each system for use in a tactical environment.

6. To determine the suitability of Doppler navigators as a primary navigation means on Federal Airways to replace any existing navigation equipment.

F. Findings.

1. Each system, as tested, satisfactorily met the requirements stated in paragraph 533c(5) of the CDOG, as modified by the contract (appendix Q).

2. Although none of the systems met all the requirements stated in the military characteristics developed for paragraph 533c(6) of the CDOG, Dopplers A and C were acceptable. Manufacturer B did not provide a rotary-wing capability. See appendix L, part III, for details.

3. Doppler C most nearly met the USAELRDL technical specifications. Doppler A met the technical specifications to an acceptable degree. Doppler B did not meet the technical specifications to an acceptable degree.

4. The overall relative order of merit of each of the systems is as follows: Manufacturer C (Dopplers C (FW) and C (RW)), Manufacturer A (Dopplers A (FW) and A (RW)), and Manufacturer B (Doppler B (FW)).

5. Doppler C was the most suitable for use in the tactical environment. Doppler A's bearing-distance indicator "fixed" during the last one-half mile to the target and remained fixed approximately two miles beyond the target. Doppler B was not acceptable because it was not designed to operate at absolute altitudes of less than 40 feet and therefore could not be used during nap-of-the-earth operations.

6. The time available for this test did not permit complete investigation to determine definitely the suitability of Doppler navigators for employment on civil airways. However, it was determined that Doppler navigators have the potential of becoming the primary aid for enroute navigation.

7. Shortcomings were found on all systems tested; deficiencies were found on Dopplers A and B. Deficiencies and shortcomings of each system are contained in paragraph C, part II, and appendices A, L, and N, part III.

G. Discussion.

1. The aircraft were to be delivered to the manufacturer in sufficient time to provide a 30-day installation and calibration period for the Doppler systems and to permit adequate time to ferry the aircraft to Fort Rucker prior to commencement of the test on 2 September 1963. The three OV-1( ) airplanes were delivered to the manufacturer on time, but the UH-19D Helicopters were not. Doppler A (FW) (OV-1) arrived at Fort Rucker as scheduled. Dopplers B (FW) (OV-1) and C (FW) (OV-1) were late because of installation and Doppler system difficulties. Doppler A (RW) (UH-19D), although not available on 2 September, did arrive in accordance with the 30-day installation and aircraft ferry time schedule and therefore cannot be considered as having been delivered late. Doppler C (RW) (UH-19D) were considerably late because Manufacturer C personnel devoted their attention to the Doppler C (FW) system. Doppler C (RW) encountered installation and Doppler maintenance difficulties which further caused a delay in delivery. Doppler C (RW) was received too late to undergo operational testing at Fort Rucker; however, operational testing was conducted by personnel of the USAAVNTBD at the USAEPG, Fort Huachuca, Arizona, concurrently with engineering tests. The late delivery of some test items resulted in a reduction of test time available.

2. All systems exceeded the maximum desirable weight stated in the military characteristics. Doppler A and C were approximately the same weight (91 pounds) and Doppler B was significantly heavier by approximately 19 percent.

3. The pictorial navigation display boards provided by the Doppler manufacturers were obtained from the same manufacturer. The pictorial navigation display boards were of different models; however, they could be interchanged and used with any of the Doppler systems tested. The pictorial navigation display board provided with the Manufacturer C system was significantly advanced in the state of the art over the other pictorial navigation display boards evaluated.

[redacted]

4. The navigational accuracy of the Doppler navigation system is dependent upon the accuracy of the sensor, computer system, and the accuracy of the heading data provided by the associated aircraft compass system. It is essential that a suitable compass and compass calibration system be provided to the operational Army units employing a Doppler navigation system. In addition, an adequate and timely distribution of maps must be accomplished to employ fully the capabilities of the Doppler system.

5. The combined sensor and computer error of each Doppler system was determined during engineering test. The relative order of merit for the systems were: Manufacturer A, Manufacturer C, and Manufacturer B. The maximum along-track errors ranged between 0.6 and 1.4 percent of distance traveled. Maximum error is defined as being 95-percent confident that 90 percent of the errors will not exceed this amount. See appendix A, part III, for details.

6. Manufacturer A's system proved to be the most reliable during the test period. It is significant to note, however, that Manufacturer A did not provide a metric readout on his computer as requested by the Army and that the other two manufacturers experienced difficulties with their equipment which had been converted to the metric system.

7. Manufacturer B's system was designed for fixed-wing application only. In the event that system was selected for fixed-wing use, a different system would be required for rotary-wing application.

8. Inherently available in Manufacturer C's Doppler system is absolute altitude information. The manufacturer has stated that an additional box would have to be added to condition the information for display purposes. This could eliminate the requirement for a separate absolute altimeter with its associated space, weight, and power requirements. It would also eliminate at least one additional antenna and possibly some interference problems.

9. Special training was required for operating and maintenance personnel.

a. The pilot and the copilot/observer training included use of the system, dead reckoning navigation, and determination of

natural cosine functions, either by use of a slide rule or from published tables. This training was accomplished in approximately 12 hours.

b. First- and second-echelon maintenance by military personnel could be accomplished by an Aviation Electronic Equipment Mechanic, MOS 284.1, with additional training. This training was estimated to require at least 16 hours of classroom instruction and 22 hours of on-the-job training. Third-echelon or higher maintenance would require extensive training. These skill levels and training requirements were determined from actual maintenance performed by the three manufacturers on their equipment during the test. The maintenance required at Fort Rucker, Alabama, is presented in part II and the maintenance required at Fort Huachuca, Arizona, is discussed in appendix A, part III .

10. The US Army Aviation Human Research Unit at Fort Rucker, Alabama, stated: (see appendix N, part III).

"a. The ManufacturerC doppler navigation system appears to be the best designed of the three systems from a human factors standpoint. All three systems have a number of human factors discrepancies which should be corrected before a system is adopted for use in Army aviation.

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"b. Use of self-contained navigational aids within the National Airspace Utilization System shall not be approved by Regional Offices prior to review by Washington Federal Aviation Agency Headquarters."

H. <u>Conclusions</u>.

1. The Doppler navigation systems of Manufacturers A and C are the most suitable of the systems tested for Army use in both fixed- and rotary-wing aircraft.

2. The pictorial navigation display board furnished with Manufacturer C's system represents the most advanced state of the art and should be considered the most suitable for Army use.

I. <u>Recommendations</u>. It is recommended that:

1. The Doppler navigation systems of Manufacturers A and C be considered suitable for Army use in both fixed- and rotary-wing aircraft.

2. The deficiencies and shortcomings listed in paragraph C, part II, and appendix L, part III, and the discrepancies enumerated in appendix N, part III, be corrected as technically and economically feasible and a confirmatory test be conducted on production models of the selected system.

3. An improved compass system and associated calibration equipment for field use, compatible with the Doppler system, be provided for Army use.

A. J. Rankin,

A. J. RANKIN
Colonel, Armor
President

PART II - TEST DATA

A. Scope.

1. Operational Testing.

a. The operational testing program was conducted by flying the fixed-wing aircraft (OV-1 ( )) over a nine-leg flight path of 508.6 nautical miles (942.6 kilometers). Geographical location values for Doppler computer inputs were obtained from the Coast and Geodetic Survey Manual (reference 2). The fixed-wing course was flown both in a clockwise and counter-clockwise direction. Altitudes flown on this course were from nap of the earth to 15,000 feet mean sea level for the airplanes. Flight speeds varied between 90 knots and 220 knots. Testing of the fixed-wing system was completed within approximately 50 flight hours.

b. Although helicopter operational testing of Doppler A(RW) was initiated at Fort Rucker by flying the helicopter course, sufficient data were not obtained for reporting purposes. (See appendix J, part III.) Helicopter operational testing was conducted concurrently with engineering testing and was completed within 20 flight hours at Fort Huachuca, Arizona.

2. Engineering Testing. Engineering testing was conducted at Fort Hauchuca. Test Bench electrical measurements and controlled in-flight data were obtained to determine component accuracies within the systems. See appendix A.

3. Flights on Civil Airways. Approximately seven flight hours were devoted to cross-country flying in the OV-1 and approximately 22 flight hours in the UH-19D to determine civil airway application.

B. Details of Test.

1. Physical Characteristics.

a. Manufacturer A System (Doppler A(FW) and A(RW).

(1) Size and Weight.

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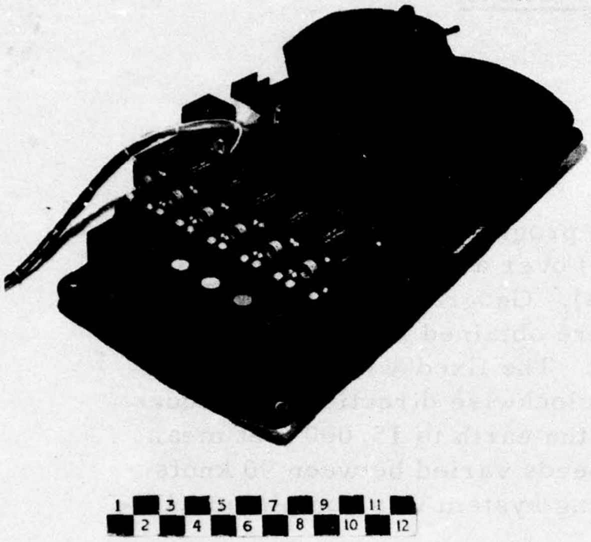

Figure 1. Doppler A receiver-transmitter unit.

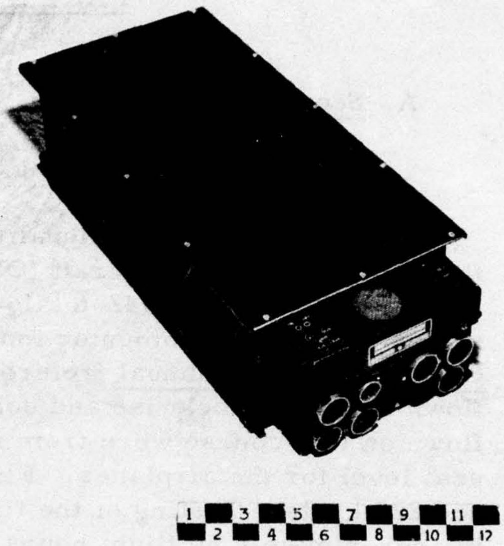

Figure 2. Doppler A converter computer unit.

Component	Size	Weight
Receiver-transmitter unit (figure 1)	7" x 13 1/4" x 25 9/16"	17 lb. 8 oz.
Converter computer chassis (figure 2)	6 5/16" x 10 1/4" x 24"	38 lb. 12 oz.
Computer indicator (figure 3)	6" x 5 3/4" x 6 7/8"	7 lb. 13 oz.
Velocity/height computer (figure 4)	4 5/8" x 3 3/8" x 6"	3 lb. 8 oz.
Control indicator (figure 5)	3 3/8" x 5 3/4" x 3 3/8"	1 lb. 10 oz.
Bearing-distance indicator (BDI) (figure 6)	3 7/8 " dia., 5" depth	1 lb. 14 oz.

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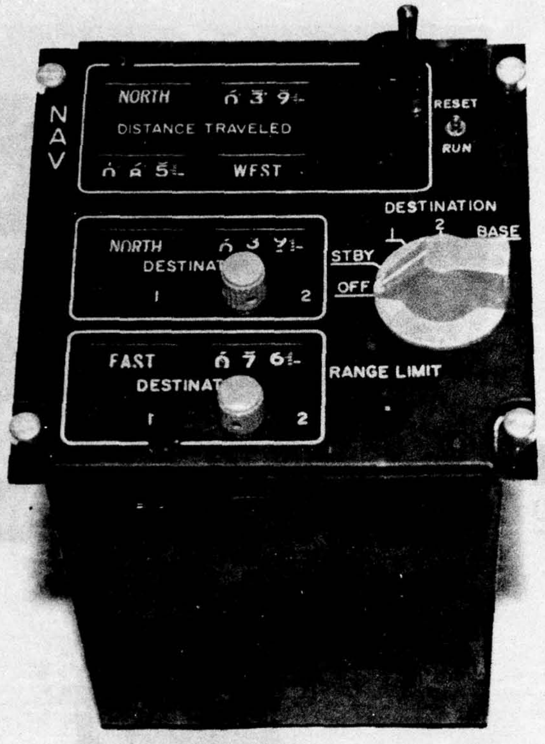
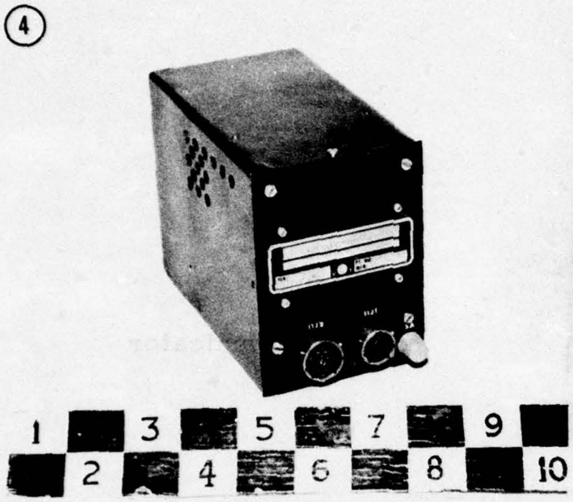


Figure 3.
Doppler A
computer indicator

Component	Size	Weight
Ground wind velocity indicator (GWVI) (figure 7)	3 7/8" dia., 5" depth	1 lb. 8 oz.
High-voltage power supply (figure 8)	5 3/4" dia., 10 1/2" depth	8 lb. 2 oz.
Pictorial navigation display board (figure 9)	10 1/8" x 9 5/8" x 3 7/8"	9 lb. 7 oz.
Hover indicator (for helicopter installation only) (figure 10)	3 7/8" dia., 3 3/16" depth	0 lb. 12 oz.

The total weight of the system was 90 lb. 14 oz.



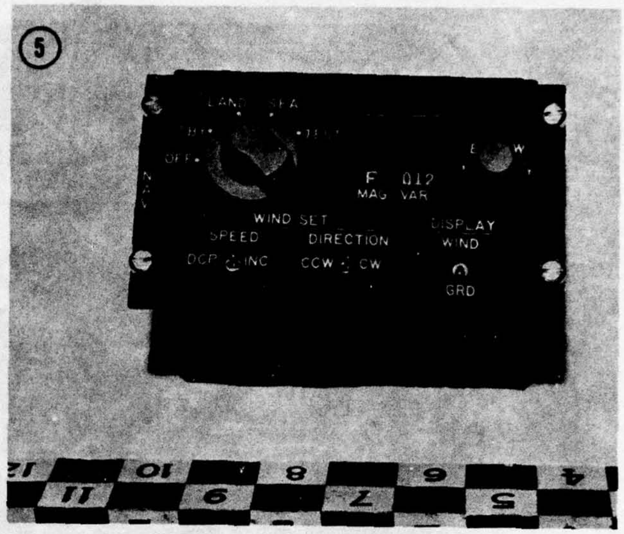


Figure 4. Doppler A velocity/height computer.

Figure 5. Doppler A control indicator.

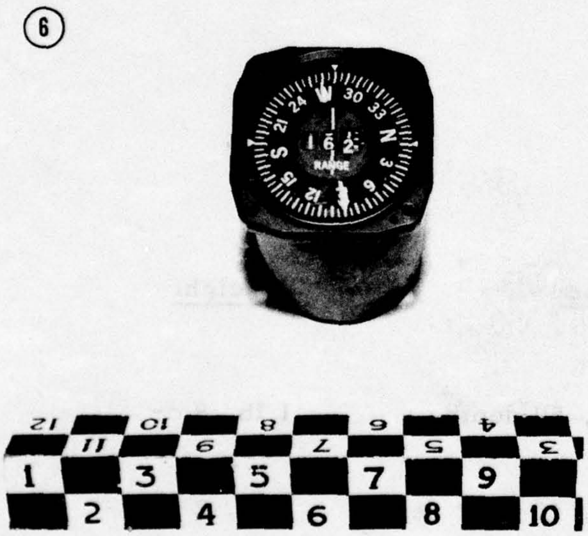
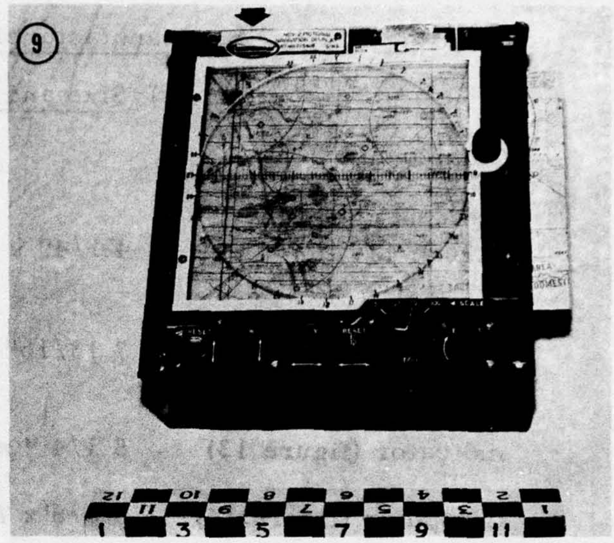


Figure 6. Doppler A bearing-distance indicator.

Figure 7. Doppler A ground wind velocity indicator.



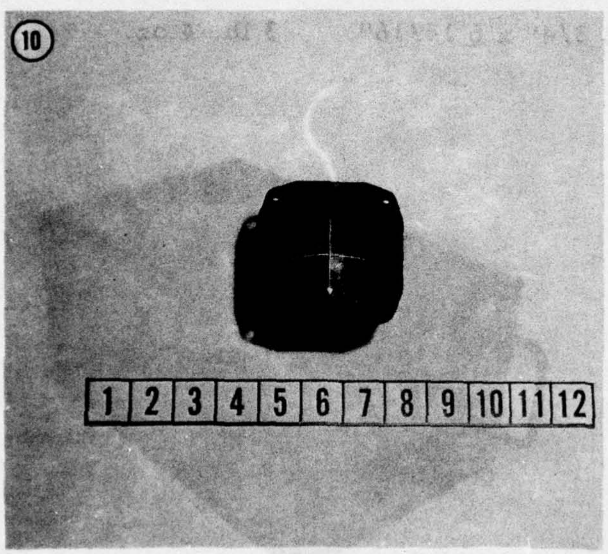


Figure 8. Doppler A high-voltage power supply.

Figure 9. Doppler A pictorial navigation display board.

Figure 10. Doppler A hover indicator.

(2) Power Requirements. The components required 115 volts a. c., 425 volt-amperes, 400 c.p.s., plus 28 volts d. c. for panel lights at 0.5 ampere.

b. Manufacturer B System (Doppler B).

(1) Size and Weight.

Component	Size	Weight
Antenna assembly (figure 11)	4 1/4" x 10 1/2" x 11 7/8"	8 lb. 14 oz.
Transmitter-receiver (figure 12)	7 13/16" x 10 3/16" x 17 7/8"	36 lb. 4 oz.
Computer control indicator (figure 13)	5 1/4 " x 5 3/4" x 9"	9 lb. 12 oz.
Computer (figure 14)	5 3/8" x 7 5/8" x 14"	25 lb. 0 oz.
Control indicator (figure 15)	2 3/16" x 5 3/4" x 6 13/16"	3 lb. 4 oz.

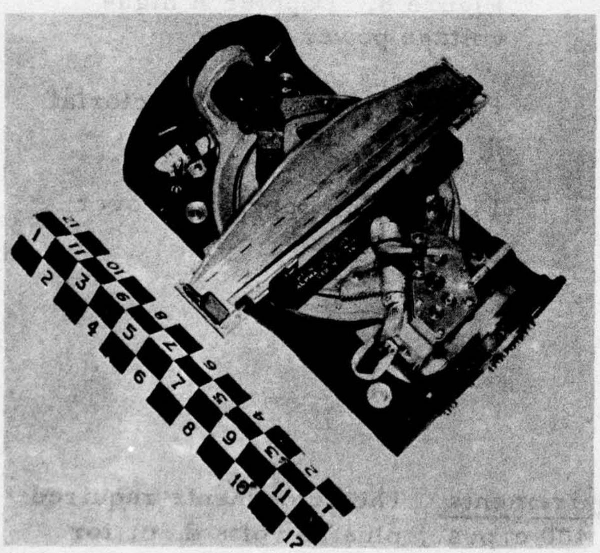


Figure 11. Doppler B antenna assembly.

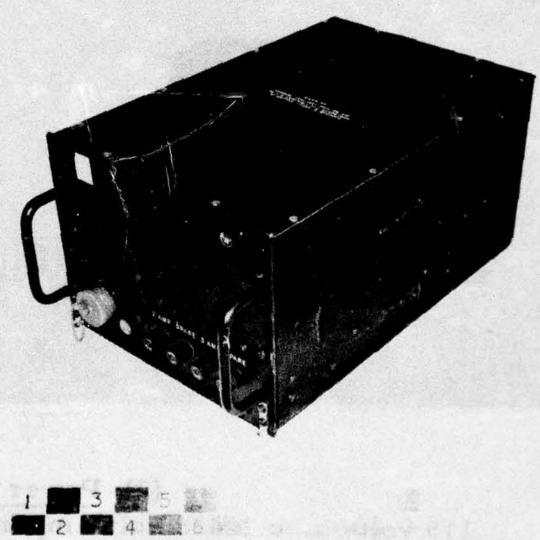
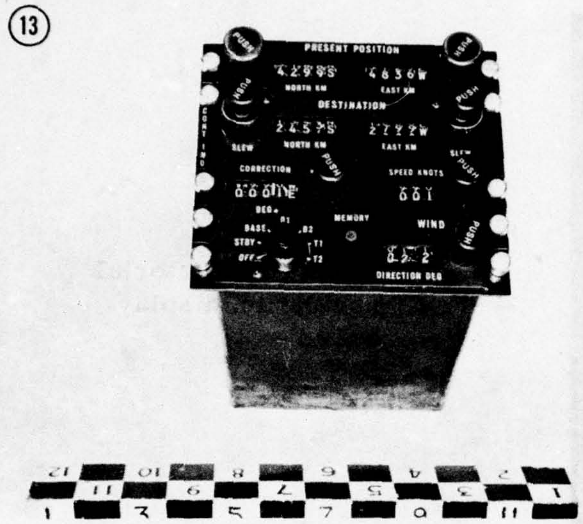
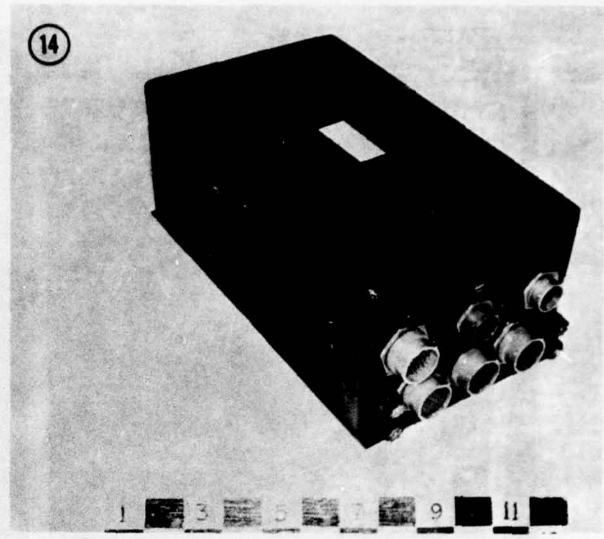


Figure 12. Doppler B transmitter receiver





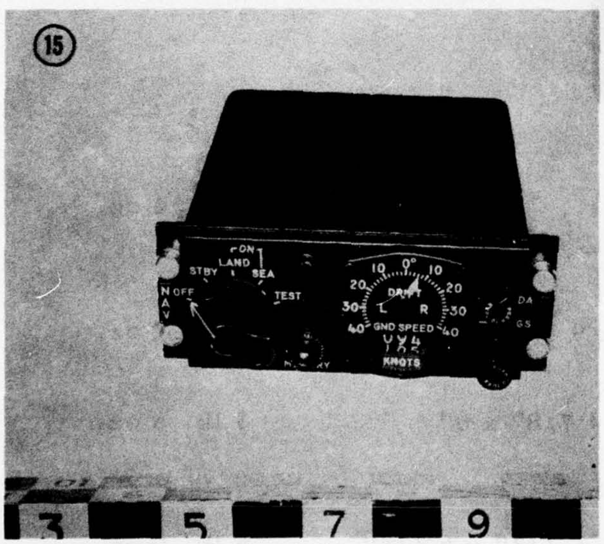


Figure 13. Doppler B computer control indicator.

Figure 14. Doppler B computer.

Figure 15. Doppler B control indicator.

Figure 16. Doppler B bearing-distance indicator.

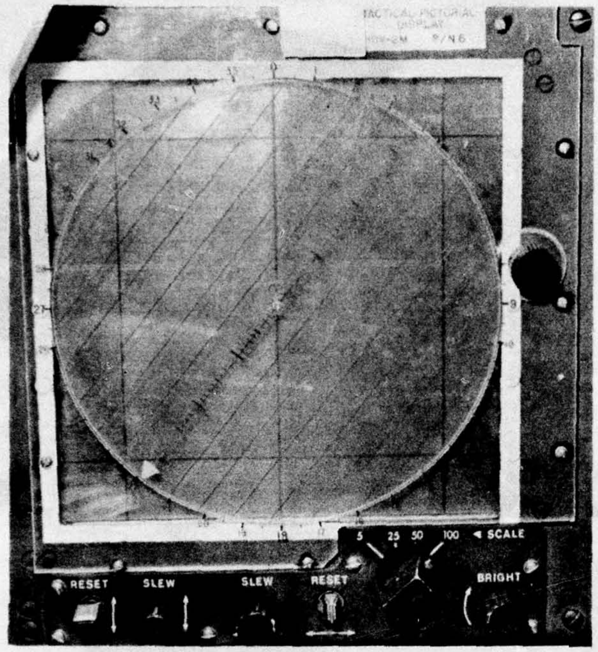


Figure 17.
Doppler B pictorial
navigation display
board.

Bearing-distance indicator (BDI) (figure 16)	3 1/4" dia., 7 5/16"	3 lb. 4 oz.
Pictorial navigation display board (figure 17)	10 1/8" x 9 5/8" x 3 7/8"	9 lb. 7 oz.
Blower, motor unit (figure 18)	4 7/8" x 4 7/8" x 6"	3 lb. 6 oz.
Velocity/height computer (2 units)* (figure 19)	6 1/32" x 5 1/2" x 6 1/2"	5 lb. 0 oz.
	8 27/32" x 6" x 6 1/2"	4 lb. 8 oz.

The total weight of the system is 108 lb. 11 oz.

*Manufacturer states that production model will consist of only the smaller unit.

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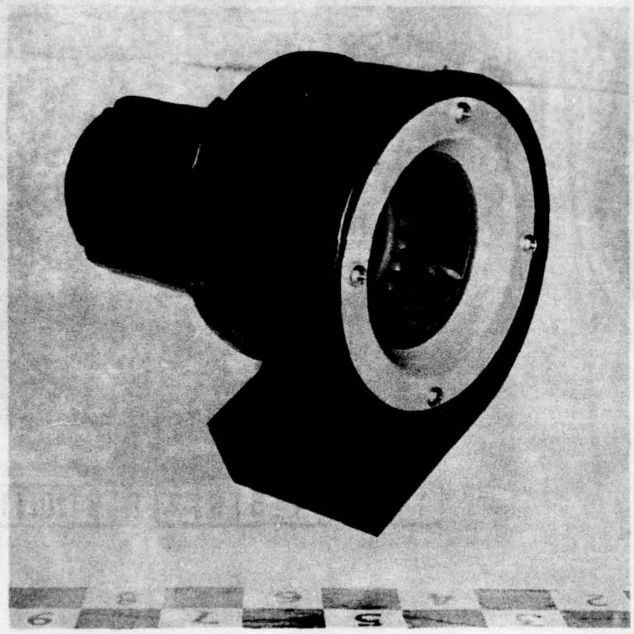
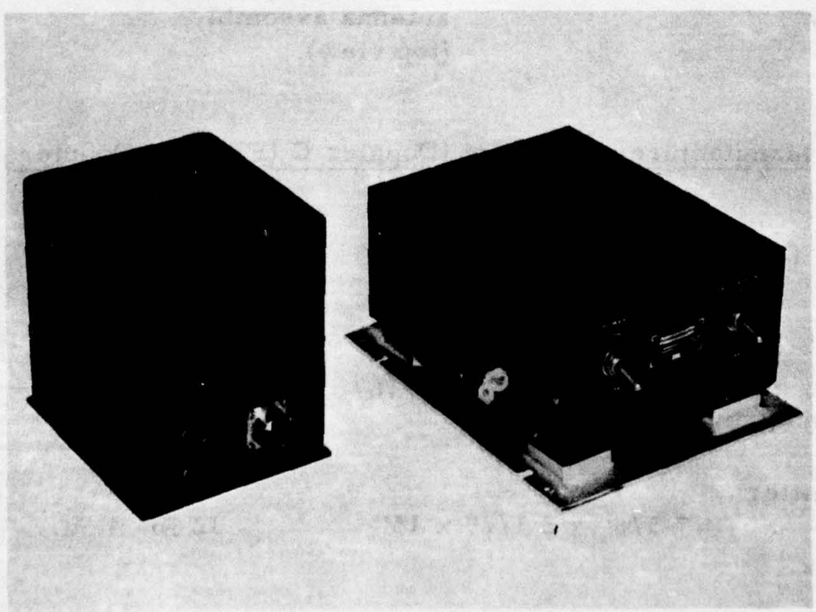
(2) Power Requirements. The components required 107 to 119.5 volts a.c., 425 volt-amperes, 380-420 c.p.s., plus 5 volts a.c. or d.c. for control panel lighting at 1.2 amperes.





(Top) Figure 18. Doppler B blower, motor unit.

(Bottom) Figure 19. Doppler B velocity/height computer(2 units).

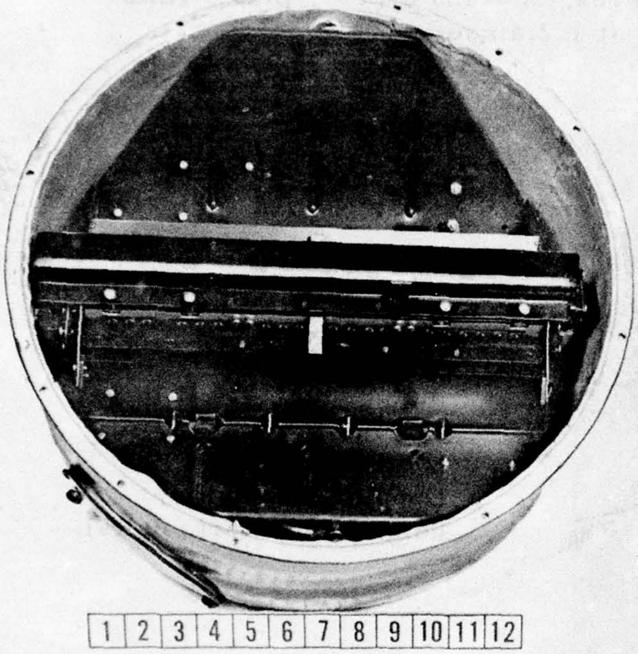


Figure 20. Doppler C antenna assembly (bottom view).

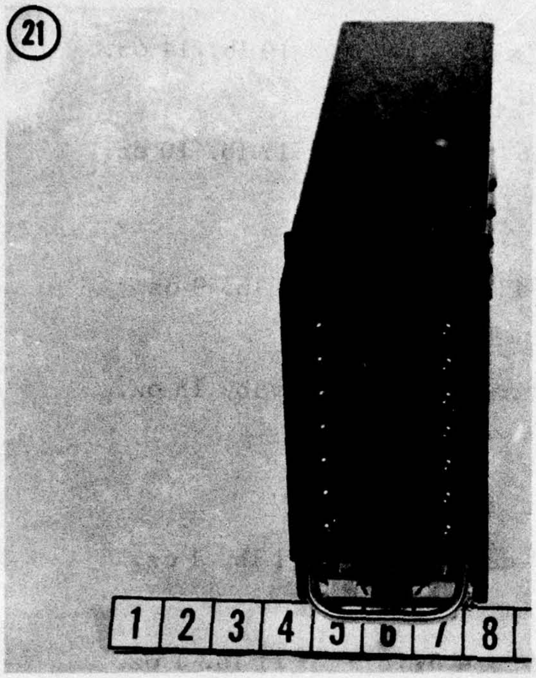
Figure 20 A. Doppler C antenna assembly (top view).

c. Manufacturer C System (Doppler C (FW) and Doppler C (RW)).

(1) Size and Weight.

Component	Size	Weight
Antenna assembly (figures 20 and 20 A)	16 7/17" dia., 7 7/16"	18 lb. 9 oz.
Receiver-transmitter unit (figure 21)	7 5/8" x 3 1/2" x 15"	12 lb. 4 oz.

21



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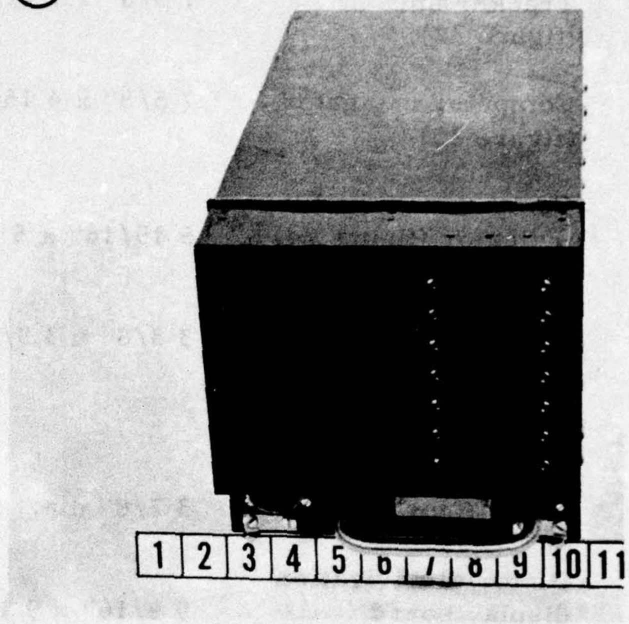

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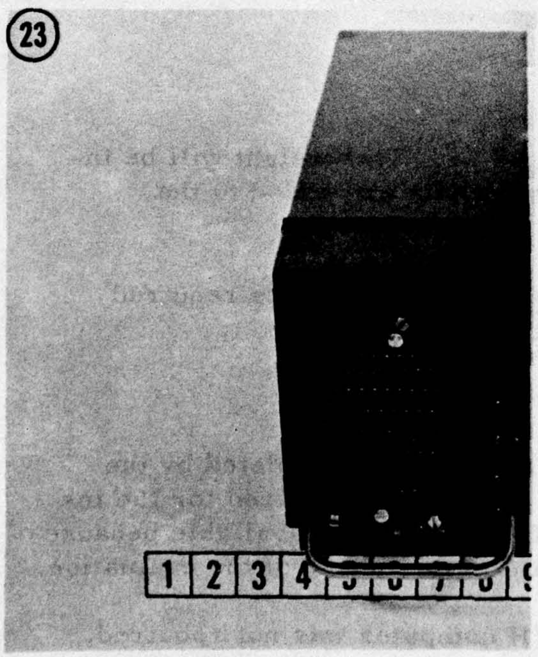

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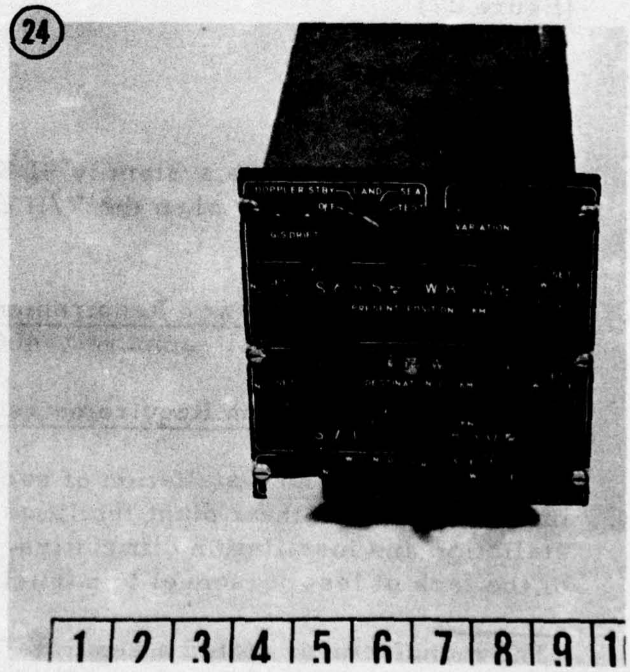

Figure 21. Doppler C receiver-transmitter unit.

Figure 22. Doppler C tracker unit.

Figure 23. Doppler C computer navigator.

Figure 24. Doppler C computer control indicator.

Tracker unit (figure 22)	7 5/8" x 7 1/2" x 15"	19 lb. 14 oz.
Computer navigator (figure 23)	7 5/8" x 4 15/16" x 15 1/16"	17 lb. 10 oz.
Computer control indicator (figure 24)	5 15/16" x 5 3/4" x 7 3/8"	7 lb. 9 oz.
Bearing-distance indicator (BDI) (figure 25)	3 3/8" x 3 3/8" x 7 3/8"	2 lb. 15 oz.
Hover indicator (for helicopter installation only) (figure 26)	3 7/8" dia., 5" depth	1 lb. 4 oz.
Pictorial navigation display board (figure 27)	9 9/16" x 9 1/4" x 4 5/16"	11 lb. 1 oz.
Velocity/height computer*		

Total weight of the system is 91 lb., 2 oz. This weight will be increased by 6-8 ounces when the V/H components are added to the components.

(2) Power Requirements. The components required 115 volts a.c., 407 volt-amperes, 400 c.p.s.

2. Installation Requirements.

a. The installation of each system was completed by the manufacturers at their plant facilities. Man-hours required for the installation and installation difficulties, if any, were not available because of the lack of test personnel to participate in this phase of the evaluation.

*The manufacturer stated a separate V/H computer was not required. The desired V/H outputs can be obtained from the basic computer. An increase of weight to this computer by 6-8 ounces can be expected.

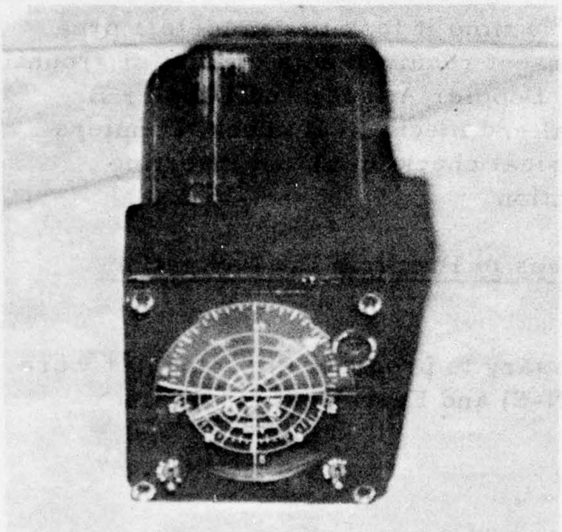

Figure 25. Doppler C
bearing-distance indicator.

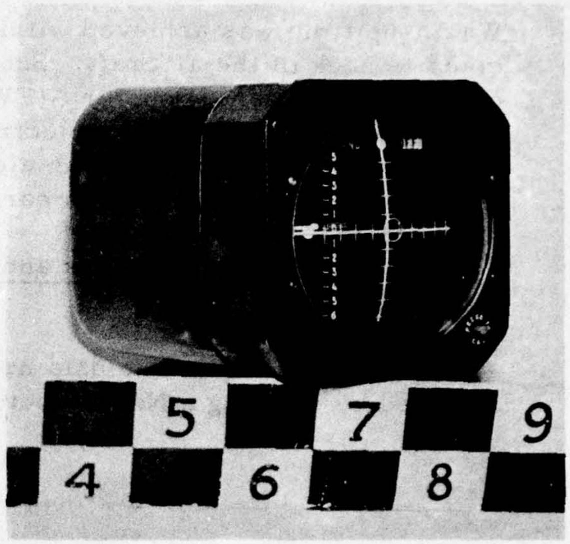

Figure 26. Doppler C
hover indicator.

b. In the fixed-wing installation, Manufacturers A and B installed their antenna in the port presently provided for installation of the AN/APN-129 Doppler antenna. The aircraft baggage compartment was modified to allow for installation of the Manufacturer C antenna. This antenna, as tested, is not compatible with the AN/APN-129 port of the OV-1( ) airplanes. The aircraft will require a structural change or the antenna must be modified to permit installation in the AN/APN-129 port of the OV-1( ). Manufacturer C did provide installation drawings (reference 27) to the US Army Electronics Materiel Agency, Fort Monmouth, New Jersey, for the installation of a modified antenna in the AN/APN-129 port.

3. Operational Characteristics. The operational characteristics were determined by employing the facilities available at Fort Rucker. Some of the facilities utilized may not be available to all the Army units in the field. Support facilities not normally available to the field units are presented in appendix M.

a. Starting Procedures. Each of the three systems was activated by switching the computer control to the STANDBY position.

Warm-up time was achieved within the time it took to complete a pre-takeoff check of the aircraft. Subsequent requirements consist of ground check of equipment (Doppler A(FW), Doppler A(RW), and Doppler B ground test provided for an electrical and mechanical check; Dopplers C (FW) and C(RW) provided an electrical check only) and inserting destination data and variation correction.

b. <u>Calculations and Steps to Program the Navigation Computer.</u>

(1) The data necessary to program the computer were obtained by drawing a North-South (N-S) and East-West (E-W) line

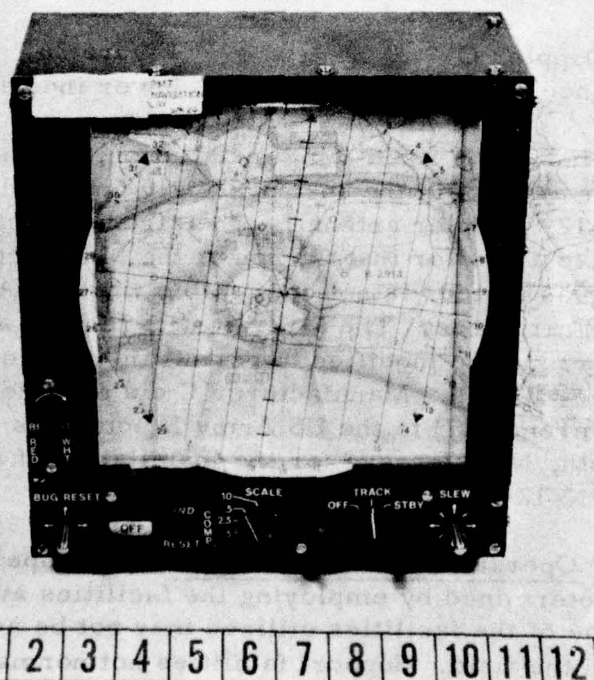

Figure 27. Doppler C pictorial navigation display board.

[redacted]

through the destination extending past the base point (departure point). The distance of the destination north or south and ease or west was then determined and this information inserted into the computer. The mean variation for the course was determined and inserted into the computer. The computation procedures required are illustrated in detail in appendix B. Dopplers B, C (FW), and C (RW) required data inputs in kilometers. Dopplers A (FW) and A (RW) required inputs in nautical miles.

(2) More accurate programming data could be obtained by use of geographic coordinates to compute N-S and E-W distances; however, this method proved time consuming and accurate geographic data were not always available. See appendix B.

c. Ease of Operation and Interpretation of Instruments and Controls.

(1) Ease of Operation. The systems were not difficult to operate. The Manufacturer C system was superior in its ease of operation.

(2) Interpretation of Instruments.

(a) Dopplers A (FW), A (RW), and B provided BDI instruments having the greatest ease of interpretation. The presentation of Dopplers C (FW) and C (RW), although more difficult to read initially, did provide additional information not available in the other two systems. The Manufacturer C hover indicator was the easiest to interpret.

(b) Each system was checked for adequacy of lighting for night operation.

1. Doppler B BDI lighting was inadequate because the distance-to-go indicator was recessed outside of the available light. Red lighting on the pictorial navigation display boards was not acceptable to illuminate the charts. The white lighting, as available, was acceptable.

2. US Army Aviation Test Board personnel examined a chart sprayed with a phosphorescent materiel to determine its possible use when employed with an ultra-violet lamp. The red lamps currently in use in the pictorial navigation display board could be replaced by

BEAUFORT SCALE

WITH CORRESPONDING SEA STATE CODES

Beaufort Number	Wind Speed	Estimating Wind Speed	
	knots	Effects observed at sea	Effects observed on land
0	under 1	Sea like mirror.	Calm; smoke rises vertically.
1	1-3	Ripples with appearance of scales; no foam crests.	Smoke drift indicates wind direction; vanes do not move.
2	4-6	Small wavelets; crests of glassy appearance, not breaking.	Wind felt on face; leaves rustle; vanes begin to move.
3	7-10	Large wavelets; crests begin to break; scattered whitecaps.	Leaves, small twigs in constant motion; light flags extended.
4	11-16	Small waves, becoming longer; numerous whitecaps.	Dust, leaves, and loose paper raised up; small branches move.
5	17-21	Moderate waves, taking longer form; many whitecaps; some spray.	Small trees in leaf begin to sway.
6	22-27	Larger waves forming; whitecaps everywhere; more spray.	Larger branches of trees in motion; whistling heard in wires.

Figure 28

ultra-violet lamps. Further testing will be required to determine fully whether this combination is acceptable.

d. Adequacy for Extended Over-Water Flights. Each system was flown over salt water (Gulf of Mexico) for a distance of approximately 62 nautical miles (115.9 kilometers). A flight over fresh water for a distance of approximately 15 nautical miles (27.8 kilometers) was also conducted. The Beaufort Sea State varied from 0 to 6 for the salt water and from 0 to 4 for the fresh water. Each system went into memory operation in the sea bias mode with a Beaufort Sea State of zero. A Beaufort Sea State of 1 or more provided satisfactory operation of all systems when operating in the sea mode. See figure 28.

e. Wind-Memory Operation.

(1) Wind-memory operation is the use of the navigation computer after loss of the Doppler signal. The last computed wind direction and wind velocity are stored in memory. This information is then used by the navigation computer to provide the computed ground speed and drift angle when a change in the aircraft heading or a change in the true air speed is made. The systems will also operate with manually inserted wind data.

(2) Doppler A (FW) was flown for an approximate distance of 30 nautical miles (55.6 kilometers) and then placed in memory operation to permit the computer to use the last sensed wind information while flying the prescribed flight course (figure 29). Dopplers B and C (FW) were flown for an approximate distance of 5 nautical miles (9.27 kilometers) and then placed into memory operation to permit the computer to use the last sensed wind information while flying the prescribed flight course (figure29A). The Doppler sensor was utilized prior to each leg of the flight outlined in figure 29A because of the shifts in wind direction and wind velocity experienced as a result of the mountainous terrain. Intially, none of the systems provided a satisfactory wind memory operation. Subsequent calibration, however, did provide satisfactory operation for Dopplers A (FW) and B over the prescribed course. Doppler C (FW) experienced a malfunction when going from Doppler to wind memory operation. The wind memory operation was reported to be satisfactory if the wind information was manually inserted into the computer. The cause of the malfunction was not determined prior to the end of the test. This was the last test of the evaluation. Position accuracy data for each are contained in appendix K.

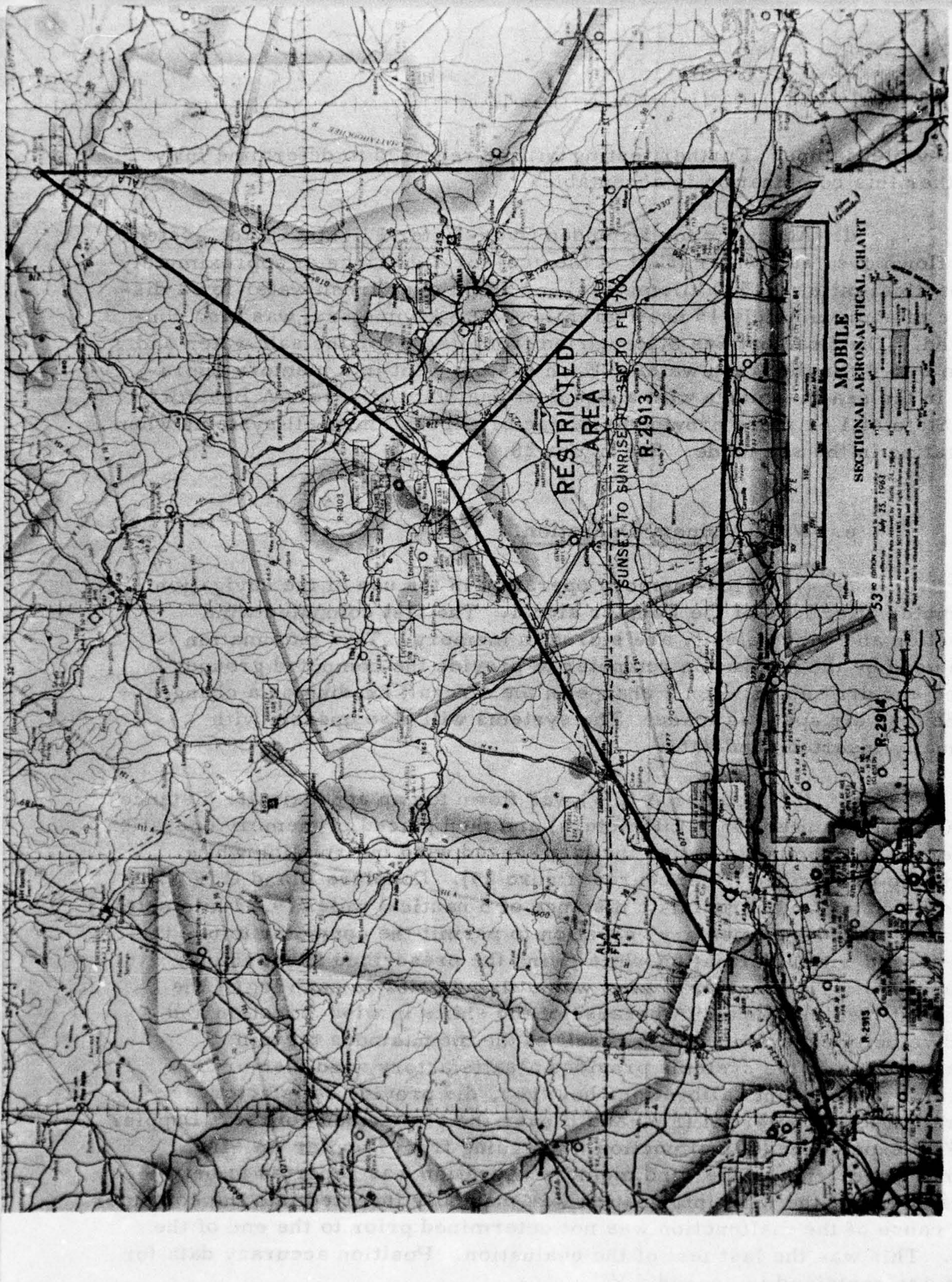

Figure 29. Flight course used for Doppler A (FW) wind-memory operation.

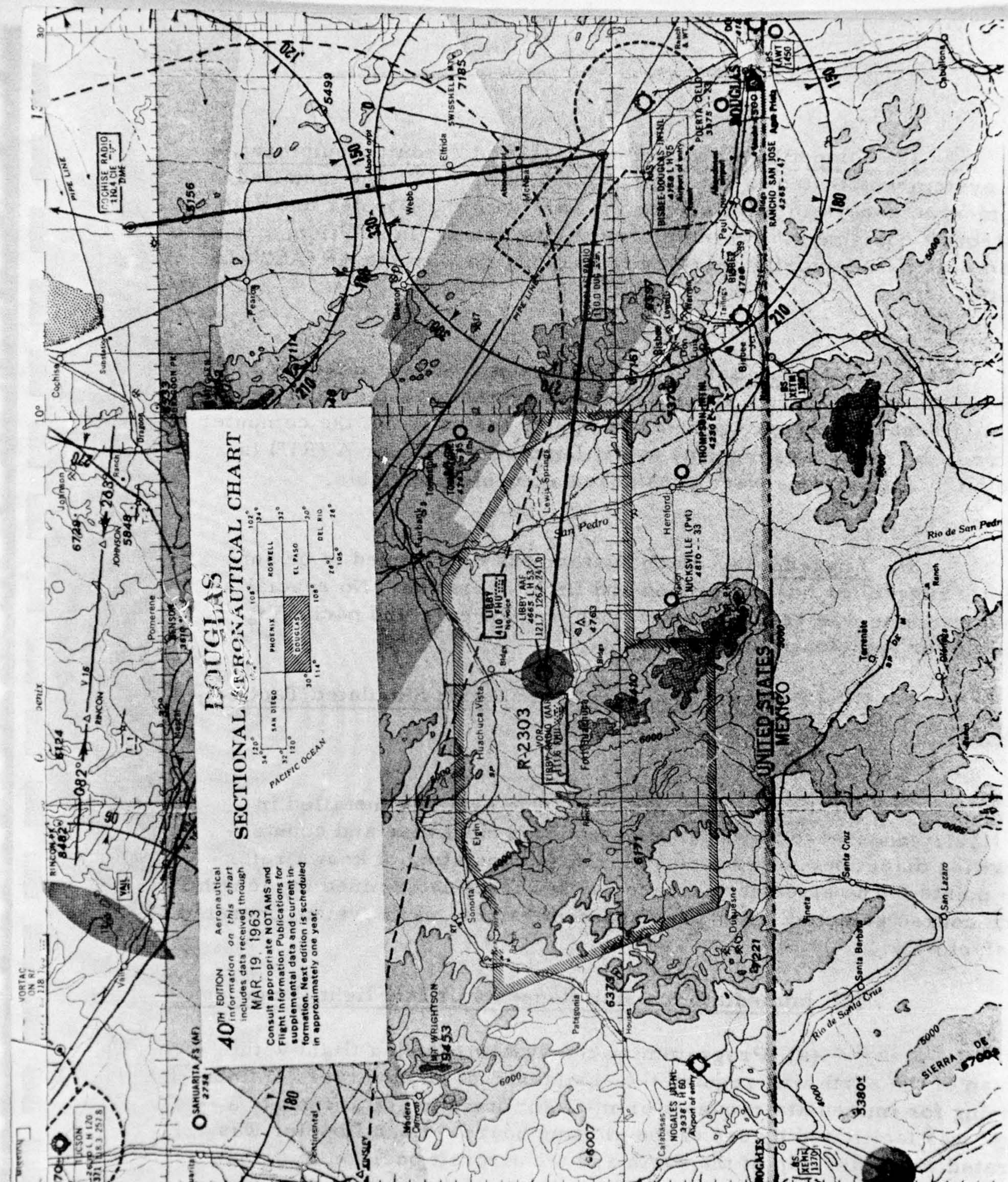

Figure 29 A. Flight course used for Dopplers B and C (FW) wind-memory operation.

f. <u>Compatibility with Other Installed Avionic Equipment.</u> Each system was tested to determine compatibility with the installed equipment to ascertain interference, if any, with the Doppler and with the aircraft equipment. No interference was noted. In addition, each system was satisfactorily operated in conjunction with the AN/ASW-12 autopilot.

g. <u>System Reliability.</u> Each system was operated for approximately 200 hours. Manufacturer A system was the most reliable. (However, the navigational computer tested is not the computer which will be provided for Army use if Doppler A (FW) or A (RW) is selected.) All systems were considered adequately reliable.

h. <u>Ruggedness.</u> Each system was determined to be sufficiently rugged for normal ground and flight operation. No special ground handling was required other than normal care and packaging expected for any electronic equipment.

i. <u>Effectiveness When Employed Under Simulated Tactical Conditions.</u>

(1) <u>Preplanned Mission.</u> The systems installed in OV-1() airplanes were flown six times in both clockwise and counterclockwise directions, over a closed course consisting of known reference points. The aircraft endurance at sea level determined the length of the course selected. For preplanned missions, each system operated satisfactorily.

(2) <u>Immediate Mission Requests or In-Flight Deviations.</u>

(a) Programming the systems during flight within the nap of the earth will require the assistance of an observer. Flight planning for immediate requests or in-flight deviation of a flight to a target was facilitated by use of the plotting board. Each Doppler was operated within the nap of the earth and the aircraft position information provided by the pictorial navigation display board was satisfactory.

(b) Assistance of the copilot/observer is required to provide a timely change of the charts. The pictorial navigation display board required the charts to be changed at the following intervals:

[redacted]

Map Scale	Miles	Time (at 200 Knots Airspeed)
1:50,000	4	1 minute, 12 seconds
1:250,000	20	3 minutes, 20 seconds
1:500,000	40	12 minutes
1:1,000,000	80	24 minutes

(3) Instrument Presentation. The bearing-distance indicator presentation supplied with Dopplers A (FW) and A (RW) was designed to "lock up" within the "electrical zone of confusion" which exists within one-half mile before, and up to two miles after, the target. This lock-up precludes an immediate return to the target within this zone. Dopplers B, C (FW), and C (RW) provided read-outs which operated through the zone of confusion without lock-up.

(4) Simulated Field Operation. Each radome was covered with mud to determine the effect when operating from unimproved strips. The maximum amount of mud that would adhere to the radome (figure 30) did not cause the sets to become inoperable during flights at absolute altitudes of 3000 feet or less. Insufficient time was available to determine the altitude at which the system would go into memory.

j. Accuracies.

(1) Operational.

(a) Accuracies which can be expected when employed in a battlefield environment were determined by flying a closed course consisting of known ground reference points. Location of these points was determined from the survey established by the Coast and Geodetic Survey Manual (reference 2). Figure 31 depicts the course flown by the OV-1( ).

(b) The error was determined at each known ground reference point by reading the Doppler navigation computer. This information has been plotted on graphs which are contained in appendices C, D, E, and F. (See appendices G, H, I, and J for the raw data.) The mean position of each known ground reference point in both clockwise and counter-clockwise direction was plotted as shown in figures 32 and 33. The

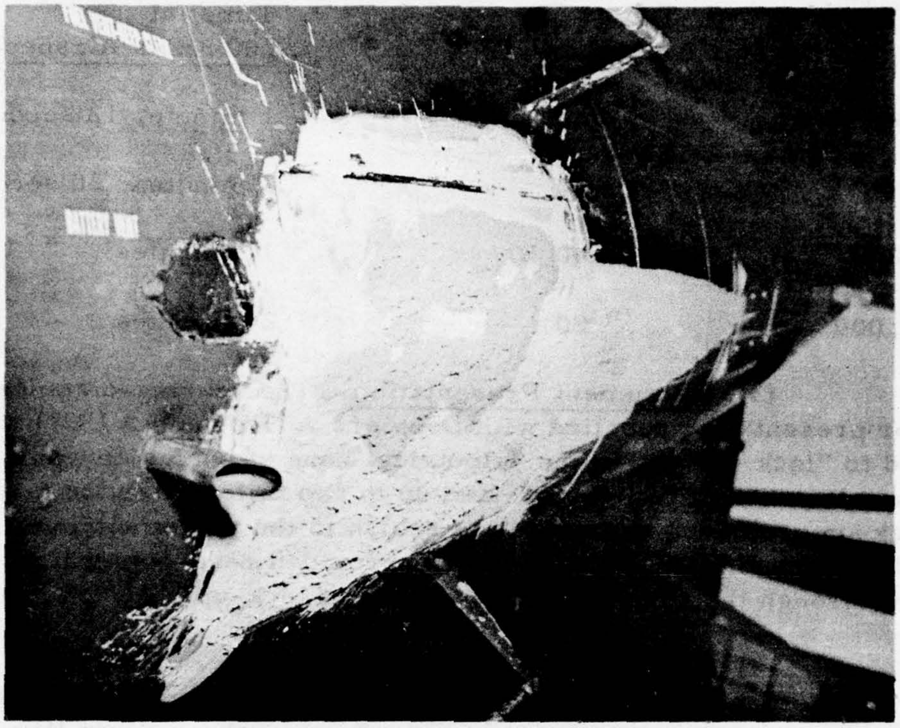

Figure 30. Mud applied to radome of OV-1( )

closure error for a flight of 508.6 nautical miles (942.3 kilometers) for the three systems is:

SYSTEM	CLOCKWISE	COUNTER-CLOCKWISE
Doppler A (FW)	0.69%	0.68%
Doppler B	0.71%	0.61%
Doppler C (FW)	0.15%	0.48%

(2) Engineering. See appendix A.

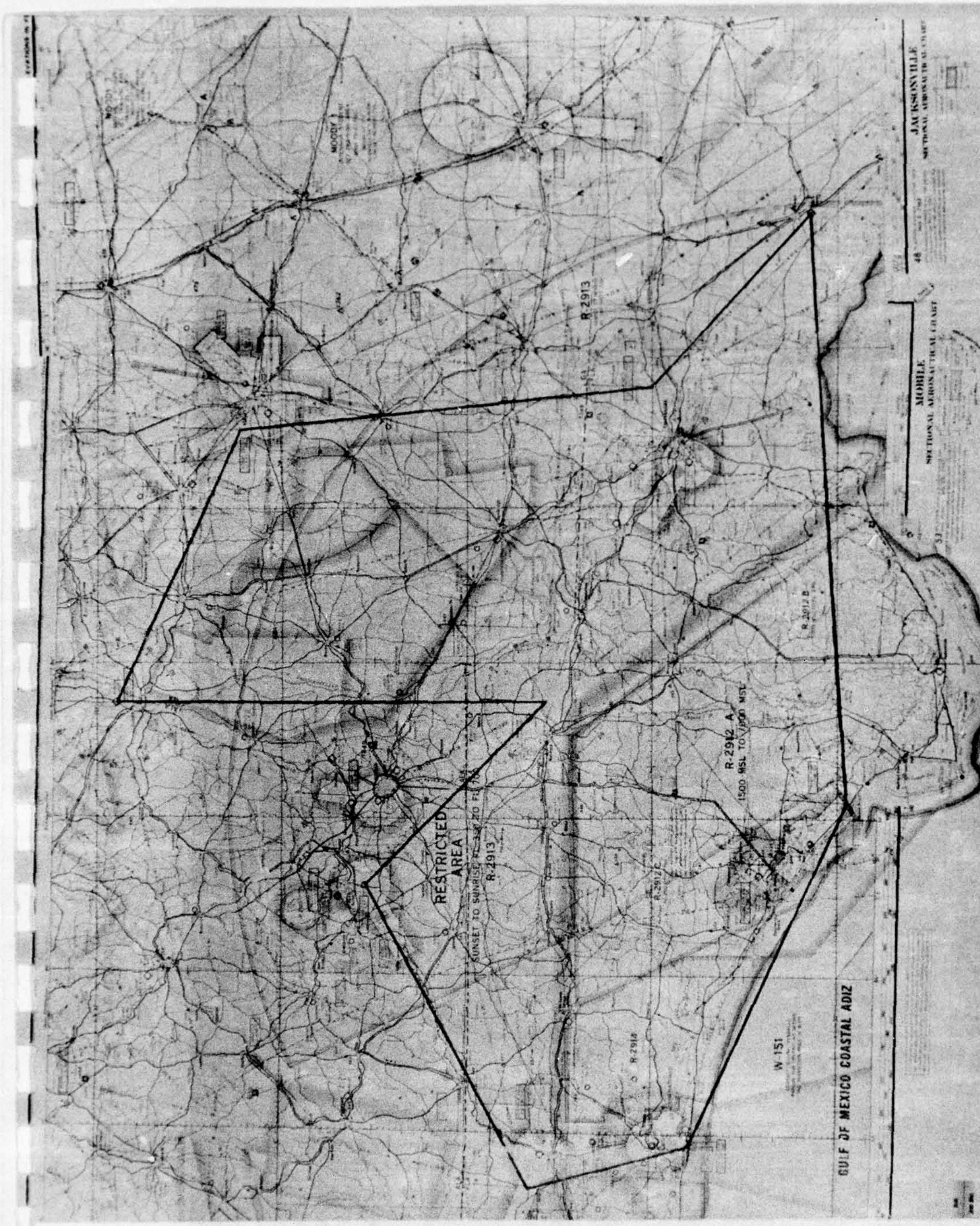

Figure 31. OV-1( ) closed flight course.

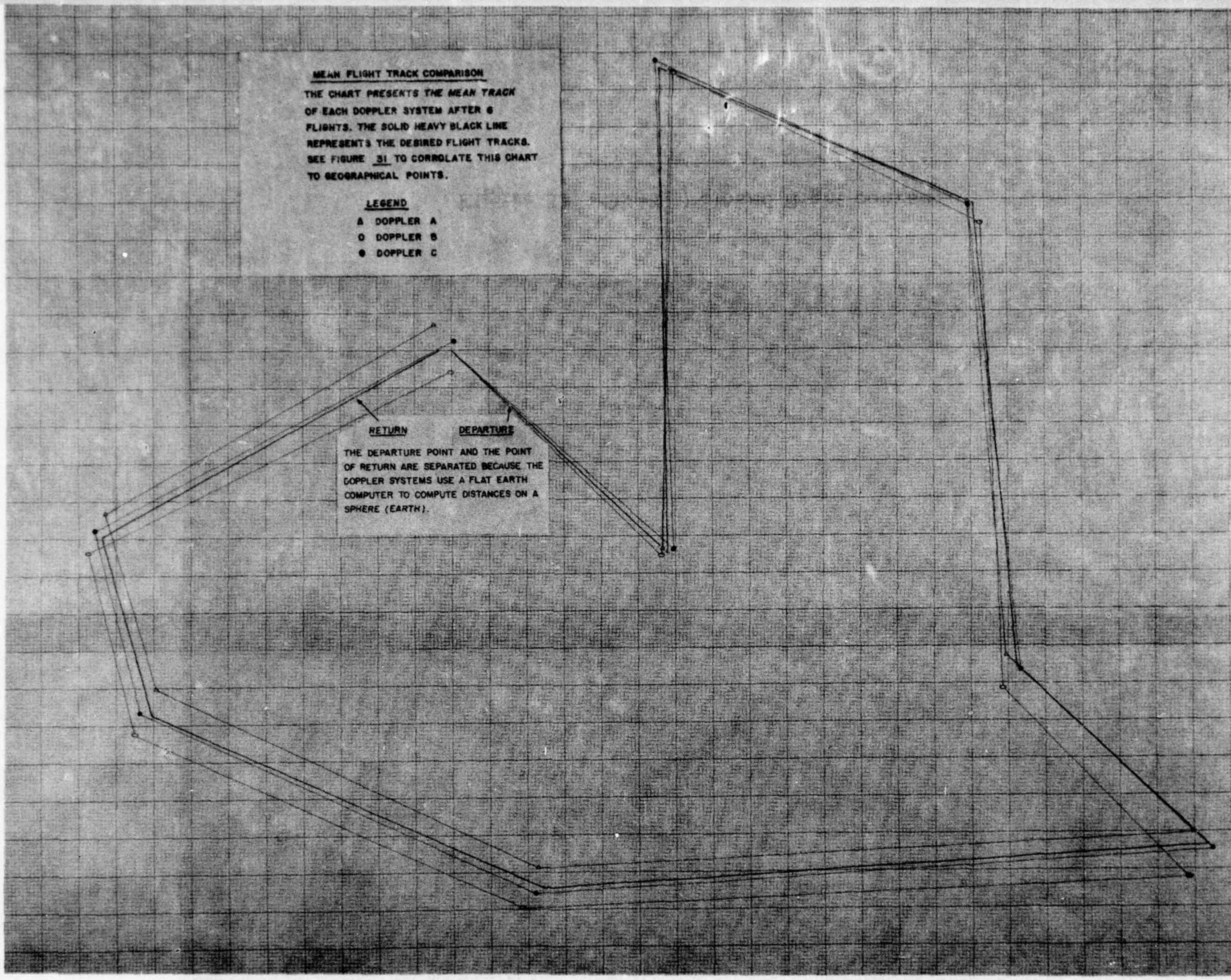

Figure 32. Closure error over OV-1( ) flight course, counter-clockwise.

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(3) System. A repeatable navigation error caused by heading reference inaccuracies could be eliminated by applying correction with the variation control. The primary consideration for system accuracy is the ability of the system to repeat.

k. Non-Essential Features. Doppler B provided a drift-angle readout. This drift-angle readout was not necessary since heading and track are available.

l. Vulnerability to Electronic Countermeasures (ECM). None of the systems were easily detected by ECM equipment (see appendix B). No attempt was made to "electrically jam" the systems. However, Doppler C (RW) was determined to have been jammed effectively by the telemetering transmitter when operating on a frequency of 246.3 megacycles. It was determined that the jamming was a result of placing the transmitting antenna too close to the radome. This transmitter is not a part of the installed avionics equipment. No interference was detected when employing the AN/ARC-55 which includes this frequency within its operating band.

m. Effects of Weather. None of the systems tested were affected by weather conditions encountered during the test. Heavy precipitation was not available during the test at a time when all three systems were operational. A comparison of the systems under adverse weather conditions, therefore, could not be made. Dopplers A (FW), B, and C (FW) were operated over a cloud deck with no adverse effects.

n. Operational Limitations Based on Aircraft Flight Limitations. None of the Doppler systems' operational capabilities were affected by the OV-1( ) airplane flight regime.

o. Low Speed and Helicopter Hover Capabilities. Both helicopter systems were flown from hover (zero groundspeed) to a maximum of 80 knots. Each system performed satisfactorily.

p. Restrictions Imposed on the Aircraft Flight Envelope. No limitations were imposed on the aircraft flight envelope. It should be noted that the OV-1 ( ) airplanes used for this test were not equipped with sensor equipment.

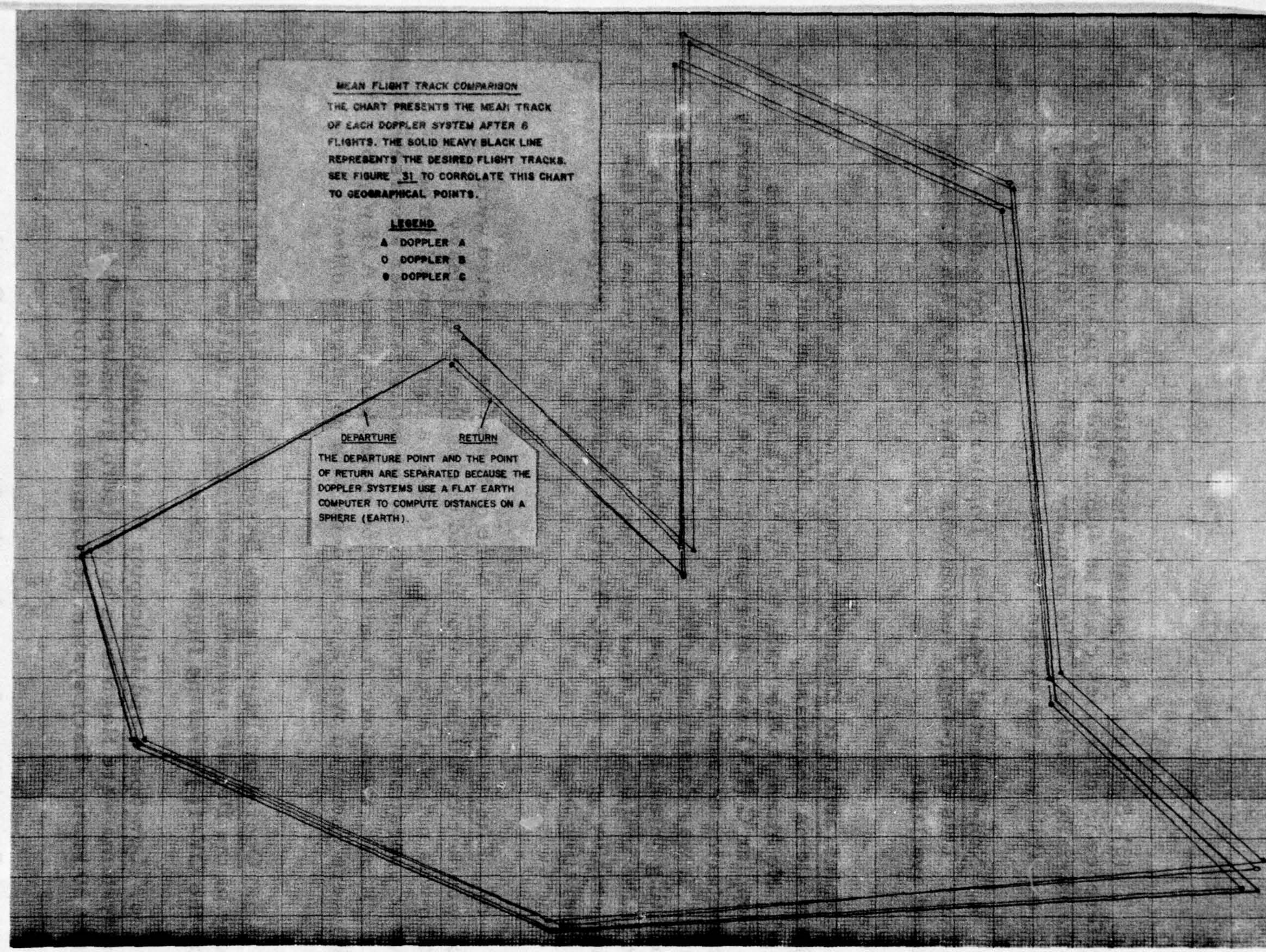


Figure 33. Closure errors over OV-1( ) flight course, clockwise.

[redacted]

3. Personnel Training Requirements.

a. Operator. A minimum of 12 hours was necessary to train adequately the operators to use any system tested. This training time included familiarization with the equipment, dead reckoning navigation, determination of geographical coordinates from maps or charts, and determination of natural cosine functions, either by use of a slide rule or from published tables. See appendix B.

b. Maintenance. Aviation Electronic Equipment Mechanic MOS 284.1 would require an additional 16 hours of classroom instruction and 22 hours on-the-job training to provide organizational maintenance.

4. Suitability for Use as a Primary Navigation Means on Federal Airways.

a. The United States' position on the use of Doppler navigation systems for use as a "short distance area coverage (NAVAID)" was stated early in 1962 to the International Civil Aviation Organization. This position, as stated, is quoted:

"(1) The United States considers that there is no functional requirement of the ATC system for Doppler navigation in the short range route environment.

"(2) The United States accepts the fact that certain aircraft will be equipped with Doppler navigators for long-range navigation and demand will be made to use it in the short-range environment.

"(3) The United States believes that the Doppler systems may be used as a short-range supplemental aid when its adequacy for navigation in the short-range system has been demonstrated.

"(4) The United States will continue to investigate the operational characteristics and advance the development of Doppler systems to exploit its full capabilities."

b. This position was taken based upon the technical limitations of the Doppler Navigation System and the adequacy and future capability of NAVAID facilities in the United States at that time. The Federal Aviation Agency (FAA) has established a project to determine the utility of Doppler Navigation Systems for the domestic environment

and to develop the required operating procedures of employment. This effort is being conducted by the National Aviation Facility Experimental Center (NAFEC) at Atlantic City, New Jersey. This testing and the results obtained should be a matter of interest to the US Army, in that the test is expected to provide answers to both technical and operational type questions now confronting the US Army. Some of the questions of specific concern are:

(1) How can errors in navigation generated by the available compass systems be isolated and eliminated?

(2) How can the errors within the Doppler and navigation computer system be determined and compensated for in both straight and level flight and during maneuvering of the aircraft?

(3) Which operating procedures developed for use at a domestic terminal area can also be applied to the tactical terminal area?

(4) Which NAVAID's now installed in Army aircraft applicable to only the domestic environment can be replaced by the Doppler set which will permit navigation for both the battlefield and the domestic environment?

5. Technical Characteristics. Each system met the Military Characteristics (reference 1) as indicated in appendix L. Detailed engineering data are contained in appendix A.

6. Human Engineering Factors. Consideration of human engineering factors was given to the operational and maintenance aspects. Dopplers C (FW) and C (RW) appear to be the best designed to meet human factors requirements. All three systems have a number of knobs, displays, labels, and indicator deficiencies to be corrected. Each system provided accessible test points for bench repair. However, each system requires special accessories such as module extenders for module trouble shooting and repair. See appendix N for a detailed human engineering test report.

7. All-Latitude Operation. Consideration was given to adequacy for all-latitude operation. Special procedures for higher latitude operation assumes greater importance because all three systems employ a flat-earth computer. The convergence of the latitudes near the poles adds to difficulty for all-latitude operation. Selection of the

correct map projection and the care exercised in plotting position relates directly upon the navigational accuracies obtained. A compass system employing a satisfactory free directional gyro to permit high-latitude operation is not available within the US Army.

8. Maintenance. Maintenance was provided by each manufacturer.

a. First- and Second-Echelon Maintenance.

(1) First-echelon maintenance consisted of daily visual and operational checks and was performed by the pilot or crewman.

(2) Second-echelon maintenance required approximately four man-hours to remove, inspect, and replace components.

b. Ease-of-Maintenance Features. The high-density packaging of each system caused difficulty in performing maintenance on modules. This high-density packaging is necessary to reduce weight and space requirements. Each system provided adequate test points which were readily accessible.

c. Standardization of Parts. The major components and subassemblies of the Doppler navigation systems are not available through Army supply channels.

d. Adequacy of Tools Available. The TK-87/U and TK-88/U Tool Equipment Sets commonly found at second-, third-, and fourth-echelon level are adequate when supplemented by a printed circuit repair kit.

e. Adequacy of Maintenance Instructions. Maintenance instructions were not furnished during the evaluation. All necessary technical information was furnished by the manufacturers.

f. Test Equipment. Standard organizational test equipment was adequate for organizational maintenance. Self-test features of the equipment were utilized in flight-line checking for go-no-go operation. However, special test and support equipment, not available in Army channels, would be required to maintain each Doppler navigation system. The following test equipment would be required for field and depot maintenance:

(1) Bench test kit, for interconnecting Doppler navigation components.

[redacted]

(2) Doppler simulator, to provide simulated aircraft flight characteristics.

(3) Spectrum analyzer for testing Doppler transmitters.

g. Maintenance Data.

(1) Doppler A did not provide a navigation computer system having a metric readout. It is significant to note that maintenance was not required on the Doppler A computer while Doppler B and Doppler C provided a metric readout and required maintenance. It can be assumed that a Doppler A system employing a metric readout may also require maintenance upon initial installation. Therefore, data collected on Doppler A (FW) and A (RW) are considered valid only for the nautical readout system tested.

(2) All repairs of modules would be performed at third or higher echelon of repair. The following maintenance was performed as indicated:

(a) Doppler A (FW) and A (RW).

Date	Discrepancy	Corrective Action
10-12 Sep 63	Pictorial navigation display board operation inaccurate.	Replaced resistor in E-W circuit.
19 Sep 63	Wind velocity readout in error.	Airspeed transducer adjusted.
19 Sep 63	Error in cross track.	N-S amplifier card loose - corrected.
20 Sep 63	Wind velocity readout in error.	Adjusted wind velocity - ground speed potentiometer.
2 Oct 63	Wind velocity readout in error.	Replaced wind-memory module in computer.

(b) Doppler B.

Date	Discrepancy	Corrective Action
7 Sep 63	Errors in cross track and long track.	Defective potentiometer in integrator unit replaced.
2 Oct 63	Cross-track error.	Replaced defective mercury leveling switch in antenna unit.
6 Oct 63	Memory light intermittent at high altitudes.	Sensitivity in receiver-transmitter unit increased.
7 Oct 63	Three-ampere computer fuze blown.	Replaced.
8 Oct 63	BDI hung up briefly on initial leg of flight.	Checked system--reason not determined.
9 Oct 63	E-W counter jamming intermittently.	Bearing on E-W shaft repaired.
12 Oct 63	Error in ground speed readout.	Replaced wind speed transducer.
14 Oct 63	N-S destination slew inoperative.	No repair was completed prior to departure of the aircraft to Fort Huachuca.
14 Oct 63	Magnetic heading readout sluggish on BDI.	Replaced BDI.

(c) Dopplers C (FW) and C (RW)

Date	Discrepancy	Corrective Action
1 Oct 63	Memory light on computer remains on.	Repaired cold solder connection in computer.

Date	Discrepancy	Corrective Action
3 Oct 63	System inoperative.	Circuit breaker in aircraft "Y" transformer popped-reset.
8 Oct 63	Doppler memory light came on intermittently.	Checked system--cause undetermined.
9 Oct 63	Doppler memory light came on intermittently.	Replaced klystron in receiver-transmitter unit.
13 Oct 63	Doppler memory light came on intermittently.	System run on bench approximately 10 hours; checked out all right. Reinstalled in aircraft.

(3) See appendix A, part III, for maintenance performed by USAEPG.

9. Civil Airway Application. The cross-country flying on civil airways was conducted between Fort Rucker, Alabama, and Fort Huachuca, Airzona, a distance of 1351 NM (2503.7 KM). Dopplers A (FW) and A (RW) provided satisfactory operation throughout the flight. The Doppler B computer and the Doppler C (FW) sensor were inoperative during the cross-country flight. Doppler C (FW) did permit the use of the navigation computer in the wind memory mode. Satisfactory wind memory operation was provided during flight. Doppler C (RW) was in an inoperable condition during the entire flight.

10. Ancillary Requirements for Satisfactory Fulfillment of the Doppler Mission.

a. The Doppler system selected for use by the US Army must be capable of permitting the pilot to accomplish his assigned mission successfully when employed in two distinctly different roles. His mission may be completed within a battlefield airspace which lacks supplemental navigation aids or it may be completed within a peace-time airspace requiring the system to be compatible for use with ground-based facilities primarily established for civil use.

b. The Doppler navigation system will necessarily generate data which will provide inputs to surveillance sensor equipment (ground speed, drift angle, present position) and provide present position and

bearing and distance information to the pilot. The accuracy of the information provided is dependent upon several factors. Some of the factors that affect the capability of the Doppler System to provide accurate position information are:

(1) Heading Reference. The compass system errors encompass a broad field but may be categorized into three areas: installation, calibration, and mechanical. Consideration must be given to each of these areas to preclude an unacceptable error in the heading reference system being used. A deviation of 1/4 to 1/2 degree can be expected when adequate care has been exercised during installation and system compensation. An error in excess of this amount is unacceptable for use with a Doppler system (reference 4). Equipment is not presently available in the Army system to calibrate compasses to this accuracy. No consideration is given to errors generated by use of a free directional gyro since the US Army does not at present have one acceptable for use with a Doppler system.

(2) Doppler Sensor and Navigation Computer. The Doppler radar and navigation computer will generate an error due to beam angular contact with the ground in the plane of the velocity vector and by the relationship between the aircraft and the earth coordinates. The error will not be significant while in straight and level flight but the error must be reckoned with during nap-of-the-earth flying when beam angular contact is most pronounced. This error can be compensated for by the use of either electronic compensation or antenna stabilization.

(3) Maps. Two scales of maps should be provided for the pilot to complete a mission. One scale is needed for enroute navigation and the second one is needed for terminal area flight. A timely and adequate distribution must be available since the use of the Doppler system is dependent usually upon inputs obtained from a map. Therefore, a navigation error can be expected because of map error, and this error will be proportionate to the accuracy of the map employed. "Doppler Charts" may be constructed after sufficient flights in an area have been completed to permit geographical locations to be plotted based on "Doppler destination." Doppler charts may be of particular significance if a timely and adequate distribution of maps is not available. The use of Doppler charts will also be of value to up-date grossly inaccurate maps. Four identical maps or charts are required for cutting to provide complete area coverage of plotting board maps including the necessary map overlap for one aircraft. A template (Figure 34) is centered over the programmed flight route, providing the outline along which the chart is to be cut.

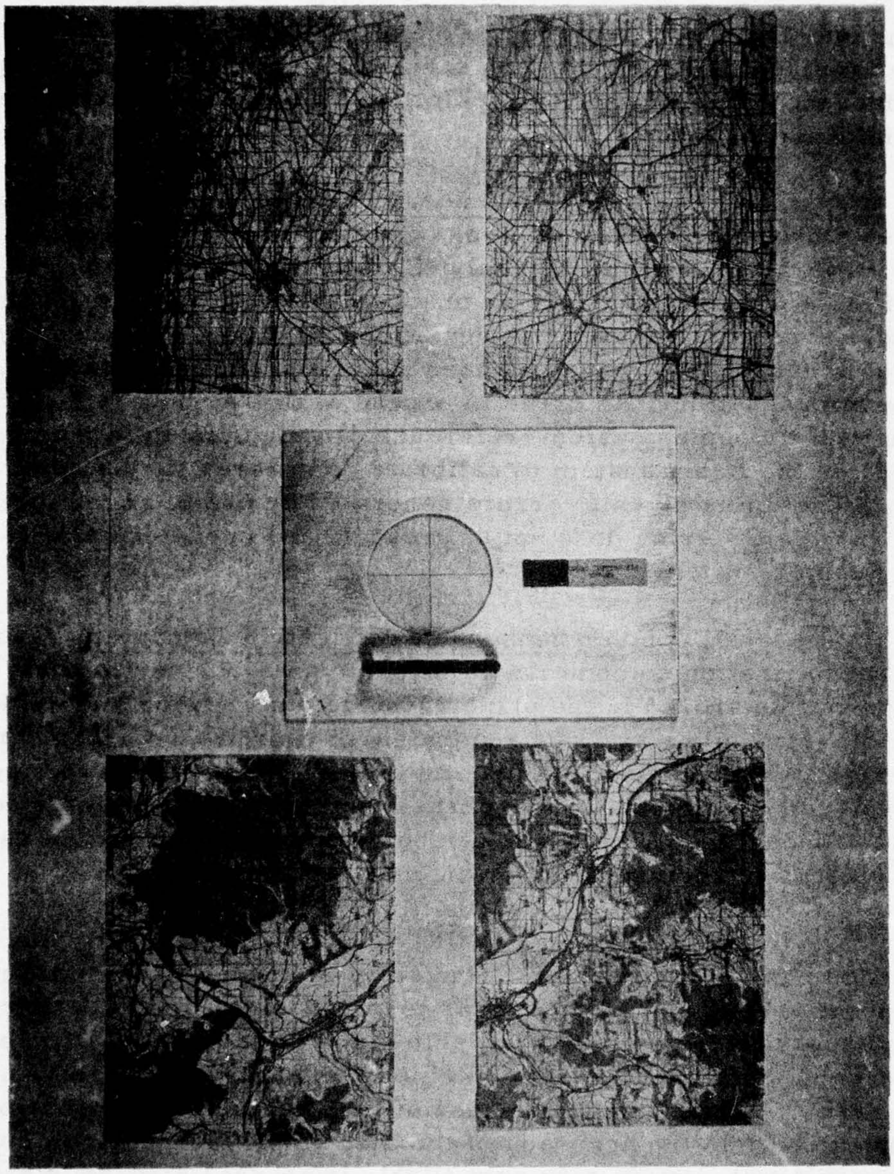


Figure 34. Template used for cutting maps.

(4) Nap-of-the-Earth Flight. The pilot cannot divide his attention to obtain coordinates from a map to program the navigation computer when flying within the nap of the earth. The computer accepts coordinates to the nearest tenth of a kilometer. (Doppler A presently uses nautical miles.) This accuracy will be difficult to read from the map during turbulent flight conditions. The use of the map board then becomes of paramount importance when completing a mission other than a preplanned one.

c. The resources presently available do not provide the means with which to minimize system errors. Specifically, the following resources are not available.

(1) There is no adequate means to complete compass swing to the degree of accuracy required. (See appendix M.)

(2) There is no standard US Army aircraft compass system available that will provide acceptable all-latitude operation.

(3) Established facilities are not adequate to provide a timely and adequate distribution of maps having scales of 1:250,000 and 1:50,000 (target or terminal area navigation and enroute charts).

d. It is desirable that the means to compensate a compass within an acceptable accuracy and a compass system that can be used for all-latitude operation be provided concurrently with the selected Doppler system. An adequate stockage of maps should also be available to the using units. A satisfactory compass system and a map or chart is needed to preclude the pilot from having to update his computer at frequent intervals, which causes him to devote much of his attention to navigation details. In addition, because of the scale factor of some imagery obtained by electronic sensors it may not be possible to correlate the imagery to a map and therefore to determine an exact location of a target identified from the imagery.

C. Deficiencies and Shortcomings.

1. Deficiencies. This paragraph contains deficiencies requiring elimination in order to make the item acceptable for use on a minimum basis.

a. Doppler A (FW) and Doppler A (RW). See appendices A and N.

Deficiency	Recommended Corrective Action	Remarks
(1) Present position and destination readouts on the computer control are presented in nautical miles.	Design a computer to provide readouts in kilometers	None.
(2) The computer does not have the capability to "lock up" the inserted coordinate values.	Provide a lock-up feature to insure the inserted data cannot change.	None.
(3) The BDI locks up during the "electrical zone of confusion" which exists from approximately 1/2 mile prior to and up to approximately 2 miles past the target.	Provide a BDI that operates continuously through the destination without exhibiting a state of electrical confusion.	It is essential that the pilot have the means to make a second pass over the target with minimum delay.

b. Doppler B. See appendices A, L, and N.

Deficiency	Recommended Corrective Action	Remarks
Doppler-2 does not provide for a hover capability	None	System was designed for fixed-wing aircraft only.

c. Dopplers C (FW) and C (RW). No deficiencies were noted.

2. Shortcomings. This paragraph contains shortcomings which are desired to be corrected as practicable, concurrently with elimination of deficiencies in paragraph 1, in production engineering, or by product improvement.

Shortcomings	Recommended Corrective Action	Remarks
a. Doppler A(FW) and A(RW). See appendices A, L, and N.		
(1) Present position control knobs protrude excessively.	Provide knobs that do not extend excessively from the face of the control head, or provide a guard to protect them.	These knobs, although not fragile, can easily be bent or broken.
(2) Magnetic variation control is not designed to accept tenths of a degree input.	Design the control to accept inputs in tenths of a degree.	
(3) The track index on the bearing-distance indicator is too small.	Provide a larger track index marker.	None.
(4) The slew rate of the counters is excessively slow when obtaining wind information and then returning to the ground function.	Provide faster cycling of the counters.	None.
(5) The destination control knobs are improperly grouped by the existing white lines.	Remove the line and mark the control knobs. In addition, provide the function of the controls by lettering the words vertically beside the knobs.	The present white marks indicate the knobs within the block are used together.
(6) The rate of slew obtainable for inserting coordinate value is inadequate.	Provide a faster drive rate, and permit continuous rotation of the counter.	Coordinate numbers cannot be inserted rapidly. For example, inserting N002 when the existing value is N400 nautical miles. This is a change of 398 digits

Shortcomings.	Recommended Corrective Action	Remarks
		and requires excessive manipulation of the controls.
(7) The vertical velocity scale on the hover indicator is not adequate.	Provide a larger scale so that the pilot can observe a rate of change sooner.	Consider a scale rate of each index to represent 100 feet per minute.
(8) Present position data cannot be updated without crossing a point twice.	Provide capability to update position data without loss of flight data or necessity of crossing a point twice.	None.
(9) No course select feature is provided.	Provide means to select a desired track through a Doppler destination and display the resulting command or error signal on a suitable instrument.	None.
(10) No light is provided on hover indicator.	Provide light for hover indicator.	None.

b. Doppler B. See appendices A, L, and N.

Shortcoming	Recommended Corrective Action	Remarks
(1) The distance-to-go readout is inadequately lighted.	Provide adequate lighting on the counter.	The counter is recessed outside the available light.
(2) The destination control knobs protrude excessively.	Provide knobs that do not protrude excessively.	None.

Shortcoming	Recommended Corrective Action	Remarks
(3) The present position and destination markings indicate only a north and east set in.	Change the markings to read north-south and east-west, as appropriate.	None.
(4) The drift angle in excess of 40 degrees cannot be determined.		The system was not designed for use in a rotary wing aircraft.
(5) The magnetic variation presentation does not have adequate index markings.	Provide index markings.	None.
(6) Present position cannot be updated without crossing a point twice.	Provide capability to update position data without loss of flight data or necessity of crossing a point twice.	None.
(7) No course select feature is provided	Provide means to select a desired track through a Doppler destination and display the resulting command or error signal on a suitable instrument	None.

c. Doppler C (FW) and Doppler C (RW). See appendices A, L, and N.

Shortcomings	Recommended Corrective Action	Remarks
(1) Excessive edge lighting is required in order to adequately light the center of the bearing-distance indicator.	Mask the edge lighting and reflect it towards the center.	The bearing-distance indicator had edge lighting.

Shortcoming	Recommended Corrective Action	Remarks
(2) The 30^{o} bearing radiacs cause instrument clutter.	Remove the 30^{o} bearing radiac.	None.
(3) A digital distance-to-go readout was not provided.	Provide a digital readout for distance-to-go.	Interpolation was required to determine distance to go to destination.
(4) A digital wind velocity readout was not provided.	Provide a digital readout for wind velocity.	Interpolation was required to determine wind velocity.
(5) The magnetic variation did not have an index marking to designate a tenth of a degree.	Provide an index marking.	None
(6) No velocity/height computer capability was provided.	Provide velocity/height computer capability.	None.
(7) Present position data cannot be updated without crossing a point twice.	Provide capability to update position data without loss of flight data or necessity of crossing a point twice.	None
(8) No course select feature provided.	Provide means to select a desired track through a Doppler destination,and display the resulting command or error signal on a suitable instrument.	None.

PART III - APPENDICES

APPENDIX A

Final Report of USATECOM Project 4-3-3600-06

Military Potential Test (Comparative Evaluation) of

AIRBORNE DOPPLER NAVIGATION SYSTEMS

December 1963

US ARMY
ELECTRONIC PROVING GROUND
FORT HUACHUCA, ARIZONA

~~FOR OFFICIAL USE ONLY~~

SUMMARY

1. The U.S. Army Electronic Proving Ground performed engineering tests of three "off-the-shelf" airborne doppler navigation systems for the purpose of developing test data to be used in selecting the system most promising for Army use. The selected system will replace the AN/APN-129 doppler radar presently installed in the OV-1B aircraft. In addition it will be installed in other Army aircraft as required.

2. A doppler navigation system is a self-contained navigator which is designed to provide the pilot with accurate navigational and control information without reference to ground-based navigational aids. The system is also designed to permit accurate navigation in all known tactical situations and under all safe weather conditions.

3. The overall results of USAEPG testing indicated that all three systems performed with reasonable accuracy. However, selection of a system most promising for army use, was based on the following findings:

a. Manufacturer A's system exhibited better accuracy and reliability in comparison to the other two systems; however due to its high cost and operational limitations, it is not considered the most promising for Army use.

b. Manufacturer B's system did not meet four of the major Technical Requirements and was the heaviest and most expensive system tested.

c. Manufacturer C's system contained many design qualities not inherent in the other tested systems and was the lightest in weight and least expensive of all tested systems.

4. It is recommended that:

a. Future development of doppler navigations systems stress an increase in accuracy and elimination of errors presently introduced by heading reference systems.

b. Early production models of the selected system be sent to USAEPG for check test.

5. USAEPG also conducted vulnerability tests which are reported on as a supplement to this report but published under separate cover.

HEADQUARTERS
U.S. ARMY ELECTRONIC PROVING GROUND
Fort Huachuca, Arizona

Final Report of USATECOM Project 4-3-3600-06

MILITARY POTENTIAL TEST (COMPARATIVE EVALUATION) OF AIRBORNE DOPPLER NAVIGATION SYSTEMS

PART I. GENERAL

A. REFERENCES.

1. Message, TT 8398, Hq. USATECOM, 17 May 1963.

2. Signal Corps Technical Requirements (SCTR) SCL-5953 Lightweight Airborne Doppler Navigation, 10 May 1963.

3. Plan of Test, USATECOM Project No. 4-3-3600-( )-G Comparative Evaluation of "Off-the-Shelf" Airborne Doppler Navigation Systems, U.S. Army Aviation Test Board, June 1963.

4. Test Plan for USATECOM Project 4-3-3600-06, Military Potential Test (Comparative Evaluation), Airborne Doppler Navigation Systems, Headquarters, USAEPG, Fort Huachuca, Arizona, ETA-115/A (-1), October 1963.

5. Message, TT 8635, Hq. USATECOM, 21 May 1963.

B. AUTHORITY.

1. Directive. Message AMSTE-BG, TT 8398, Headquarters, U.S. Army Test and Evaluation Command, Aberdeen Proving Ground, Maryland, to CG, U.S. Army Electronic Proving Ground (USAEPG), Fort Huachuca, Arizona, 17 May 1963.

2. Purpose. To conduct a military potential test (comparative evaluation) of "Off-the-Shelf" Airborne Doppler Navigation Systems for the purpose of developing test data for use as a basis for selection of the most promising system for Army use.

3. Responsibilities. The message designated the U. S. Army Aviation Test Board, Fort Rucker, Alabama, as the Coordinating Test Authority (CTA) and the U. S. Army Aviation Test Activity, Edwards Air Force Base, California, and the USAEPG as Participating Test Authorities.

C. DESCRIPTION OF MATERIAL.

1. A brief description of each system follows:

a. Manufacturer A. This company's system consists of 12 units with a total weight of approximately 91 pounds. The system requires approximately 400 v.a. of 115 volts, 400-cycle power. Major components of the system are:

(1) Doppler Radar.

(2) Computer Group.

(3) True Air Speed Transmitter.

(4) Altimeter Coupler.

(5) Map Display.

b. Manufacturer B. This company's system consists of 9 units weighing approximately 108 pounds. The system requires approximately 615 v.a. of 115 volts, 400-cycle power. Major components of the system are:

(1) Navigation Radar Set

(2) Navigation Computer

(3) True Air Speed Transmitter A-1

(4) Bearing, Heading, Distance Indicator ID-663/U

(5) V/H Computer Unit

(6) Map Display

c. Manufacturer C. This company's system consists of 9 units with a total weight of approximately 91 pounds. The system requires approximately 450 v. a. at 115 volts, 400 cycles. Major components are:

(1) Antenna

(2) Receiver Transmitter

(3) Frequency Tracker

(4) Hover Indicator

(5) Navigation Computer

(6) Velocity and Steering Indicator

(7) Control Indicator

(8) Map Display

(9) True Air Speed Transmitter

2. A basic doppler navigation system consists of the following items:

a. Doppler Sensor. The doppler sensor is a device which transmits microwave energy to the ground in narrow beams and measures the frequency shift (doppler effect) of the returned energy. This frequency shift is converted into electrical outputs which represent the movement of the aircraft in terms of forward ground speed, drift, and vertical velocity.

b. Navigation Computer. The navigation computer takes the output of the doppler sensor and combines it with data from the heading reference and true airspeed transducer. The resulting solution of vector equations using this data provides outputs of ground speed and direction, drift angle, wind speed, and wind direction. When these are coupled with known starting position and desired destination, read-outs of present position and distance and direction to destination are made available to the pilot.

c. Map Display Unit. The map display unit takes information from either the doppler sensor or the navigation computer and presents it in the form of a reticle positioned over a section of a conventional map or chart as a representation of the aircraft position over the ground.

D. BACKGROUND.

1. Two separate airborne navigation requirements are contained in the Combat Development Objectives Guide. One requirement cites a specific type of self-contained navigator, (reference a, paragraph 533c(5)). The second requirement specifies a need for a Navigator, Lightweight, Self-Contained (reference a, paragraph 533c(6)). Both requirements are classified Confidential.

2. A doppler navigation system (AN/APN-118) was under development for Army use but failed to meet Army requirements and the program was terminated prior to completion.

3. As a result of the joint USAECOM-USATECOM EMTEP conference at Fort Monmouth, New Jersey, 10-11 April 1963, it was proposed that an evaluation of commercial "Off-the'Shelf" doppler navigation systems be conducted. USAMC concurred in the proposed evaluation and directed an expedited program to furnish an overall comparative evaluation report by 30 November 1963.

4. Industry was solicited to determine the available "Off-the-Shelf" systems having a military potential. Five manufacturers subsequently submitted their proposals to the Army for review to determine their adequacy for further consideration.

5. Three manufacturers' proposals were accepted on 24 June 1963, providing a total of five systems for test. Manufacturers A and C each agreed to provide a system for both a fixed- and a rotary-wing aircraft. Manufacturer B agreed to provide a system for fixed-wing aircraft only.

6. The five aircraft containing the test items arrived at the USAEPG during the period of 16-18 October 1963.

7. The special instrumentation package used for this evaluation arrived at the USAEPG on 7 November 1963.

8. The test was completed on 6 December 1963. The aircraft were released by the USAEPG on 9 December 1963 to be returned to the respective manufacturers for removal of the test items and return of the aircraft to standard configuration.

E. TEST OBJECTIVES.

1. General Objective: To determine which of the systems tested most nearly meets or exceeds current QMR/MCs.

2. Criteria: The criteria against which these systems were tested are contained in Signal Corps Technical Requirement (SCTR) SCL-5953, Lightweight Airborne Doppler Navigation, 10 May 1963, which is classified Confidential.

3. Concept of Employment: The doppler navigation system which is selected as a result of this comparative evaluation will be installed in U.S. Army aircraft. It will replace the AN/APN-129 doppler radar presently installed in OV-1B aircraft.

A doppler navigation system provides the pilot with accurate navigational and control information without reference to ground based navigational aids. Such a system permits accurate navigation in all known tactical situations and under all weather conditions deemed safe for flying.

4. Concept of Testing: The airborne flight tests were conducted in separate rotary-wing and fixed-wing phases. Both phases utilized the AN/FPS-16 and a ground control station located at Fort Huachuca to provide accurate space position information. Information from the test item was telemetered to the ground station for time correlation with the radar information.

The data was processed and separated into two parts; i.e. along-track error and across-track error. The analysis of the data so separated permitted elimination of systematic compass system induced errors.

F. DISCUSSION:

It is considered important to state that all installations were prototype. Therefore various changes could be expected in a production type installation. Manufacturer A, Manufacturer B, and

Manufacturer C, hereafter called A, B, and C, could expect an improvement in accuracy and calibration of their respective systems. B and C could expect an improvement in reliability. None of the systems tested meets the absolute accuracy requirement stated in SCTR SCL-5953. However, Company A's system provided the best accuracy.

The overall results of the engineering test indicate that all three systems operated with reasonable accuracy. This finding is based on the estimated of the standard deviations obtained from the flight test data on each system. Any mean along-track error is assumed to be a calibration error or a systematic error which can be eliminated.

The mean across-track error was treated in the same manner after systematic compass system errors had been eliminated. (See Table 5)

The overall comparison, point by point, of the technical requirements is shown in Table 4. In this table it is shown that the system submitted by B *falls short on four of the important* requirements.

While at USAEPG the systems submitted by A exhibited excellent reliability in relation to the equipments submitted by C. The reliability information, which is tabulated in Paragraph D, Phase I, of Part II, includes comments which point out several pertinent facts. C spent more time maintaining his equipment than did A; however, his failures were intermittent and therefore required more time to locate. Two problems plagued C and resulted in the major portion of this maintenance time.

In the helicopter system, C might have been using a bad power source throughout the test as the inverter failed just prior to completing the airborne tests. The bad power source would account for almost all of the problems C had with doppler System No. 5, i.e. failure of power transistors in both the low voltage and high voltage power supplies, frequent short periods of memory operation, and failure of the hovering indicator to respond properly at times.

Manufacturer C had problems with the coupling to the autopilot. However, the scale factor on the doppler input was found to be

correct and the fault would appear to be in the autopilot, not the doppler. C had an additional problem with wind memory operation; the problems were not located while at the USAEPG. Previous comments from the pilots indicated that the memory operation was quite satisfactory prior to delivery of the aircraft to the USAEPG.

The True Air Speed transducer utilized by C in the helicopter is unsatisfactory as it does not go below about 60 knots. The manufacturer's representatives indicated that they were not familiar with the item and therefore could not repair it.

Due to the short lead time involved in the program C did not provide a V/H computer. This was due to the fact that the manufacturer could not obtain a precision non-linear potentiometer to obtain the precise non-linear scale factor required. However, provisions were made to include the V/H computation in the normal navigational computer in the event the potentiometer was acquired during the evaluation.

TABLE 1

MANUFACTURER A

Technical Characteristics

1. Horizontal velocity limits: -50 kts to + 350 kts
2. Vertical velocity limits: ± 10,000 fpm
   0 to ± 3,500 fpm displayed on hover indicator
3. Drift Angle Limits: 0 to ± 180°
4. Altitude limits and attitude limits: minimum = 0 ft absolute
   @ 25,000 ft MSL pitch limit = 30°, roll limit = 60°
5. Range: 500 nm = 926 km
6. Preflight Warmup and Calibration Time: 5 minutes
7. Antenna Area: 358.4 sq. inches
8. Radiated Power: 1.65 watts
9. Number of Destinations: Two and Base
10. Special Test Equipment: 20 items, 136 pounds (estimated)
    (not production line at present)
11. V/H computer accuracy: within specification
12. Transmitter frequency: 13,300 Mc.
13. Present Position Accuracy: See Table 5

TABLE 2

MANUFACTURER B

Technical Characteristics

1. Horizontal ground velocity limits: +40 kts to +800 kts

2. Vertical velocity limits: None

3. Drift angle limits: ± 40 degrees

4. Altitude limits and attitude limits: minimum = 40 ft absolute @ 25,000 ft MSL pitch limit = 15°, roll limit = 20°

5. Range: 999.9 km

6. Preflight warmup and calibration time: 5 minutes

7. Antenna Area: Swept area = 131.39 sq. inches

8. Radiated Power: 17.8 watts

9. Number of Destinations: Two and Base

10. Special Test Equipment: 4 items, 135 pounds (already militarized)

11. V/H computer accuracy: Scale factor wrong

12. Transmitter frequency: 13,325 Mc. ± 30 Mc

13. Present Position Accuracy: See Table 5

TABLE 3

MANUFACTURER C

Technical Characteristics

1. Horizontal ground velocity limits: -50 kts to +500 kts

2. Vertical Velocity limits: None
   0 to ±5,000 fpm displayed on Hover Indicator (two ranges)

3. Drift Angle limits: 0 to ± 180°
   displays 0 to ± 90°, track angle changes 180°

4. Altitude limits and Attitude limits: minimum = 0 ft absolute
   @ 25,000 ft MSL pitch limit = 25°, roll limit = 40°

5. Range: 999.9 km

6. Preflight warmup and calibration time: 5 minutes

7. Antenna Area: Swept area = 226.87 sq inches

8. Radiated Power: 0.275 watts

9. Number of Destinations: Two

10. Special Test Equipment: 4 items, 80 pounds

11. V/H computer accuracy: None provided

12. Transmitter frequency: 13,325 Mc.

13. Present Position Accuracy: See Table 5

Signal Corps Technical Reg. SCL-5953-para. number	Manufacturer A	Manufacturer B	Manufacturer C
3.1.1.1	Yes	Yes	Yes
3.1.1.2	Yes	Yes	Yes
3.1.2	Yes	Yes	Yes
3.1.4	Yes	Yes	Yes
3.1.5	Yes	Yes	Yes
3.2.1	Yes	No	Yes
3.2.2	Yes	Yes	Yes
3.2.3	Yes	No	Yes
3.2.4	Partial	No	No
3.2.5	Partial	Yes	Yes
3.2.7	Yes	No	Yes
3.2.8	Yes	Partial	Yes
3.2.9	Yes	Yes	Yes
3.3.1	Yes	Yes	Yes
3.3.2	Yes	No	Yes
3.4.1	Yes	Yes	Yes
3.4.2	Yes	No	Yes
3.4.3	Partial	Yes	Yes
3.4.4	Partial	Yes	Yes
3.4.4.1	Yes	Yes	Yes
3.4.5	No	Yes	Yes
3.4.6	Yes	Yes	Yes
3.4.7	Yes	Yes	Yes
3.4.8	No	No	No
3.5	Yes	Yes	Yes
3.5.1	Yes	Yes	Yes
3.5.2	Yes	Yes	No
3.5.2.1	Yes	Yes	Yes
3.5.3	Yes	Yes	Yes
3.5.5	Yes	Yes	Yes
3.6.1	No	No	No
3.6.6	Yes	Yes	Yes
3.6.7	Yes	Yes	Yes
3.7	Yes	Yes	Yes
3.7.1	Yes	Yes	Yes
3.7.2	Yes	Yes	Yes
3.7.3	Yes	Yes	Yes
3.7.4	Yes	Yes	Partial
3.7.4.1	Yes	No	N/A
3.8.1	Yes	Yes	Yes
3.16.1	Yes	Yes	Yes
3.16.2	Yes	Yes	Yes
3.12	No	No	No

It is questionable whether the attitude vs altitude results shown in Tables 1-3 are really representative of the limitations of the equipment. With these systems the only way to cause them to go into memory is to lift the beams off the horizon or to exceed the acceleration capabilities of the frequency tracker. Geometrically none of the systems performed in accordance with their capabilities. This portion of the test was not instrumented and therefore the results are not guaranteed to be accurate.

Manufacturer C has several factors in his favor. C has provided a place in the navigational computer for his V/H computer, resulting in a smaller volume and a smaller number of "black boxes". Inherently available in C's doppler system is absolute altitude information. The manufacturer has stated that an additional box would have to be added to condition the information for display purposes. This could eliminate the requirement for a separate absolute altimeter with its associated weight and power requirements. It would also eliminate at least one additional antenna and some possible interference problems. Manufacturer C's system has the highest growth potential of the 3 systems.

The velocity steering indicator provided by C is the only indicator submitted which provides a continuous visual indication of bearing and distance to destination all of the way to the destination. The indicators provided by A and B "lock-up" at a distance of 1.5 nm from the destination. The method utilized by C to obtain the zero speed or hover capability has greater inherent accuracy than the method used by A.

A experienced some interference problems with the telemetry signal (246.3 Mcs) radiated from a blade antenna approximately one foot from the doppler antenna. This appeared to be the cause of memory operation of the system.

The deterioration of system accuracy in the helicopter configuration leads to the conclusion that the doppler error contains a portion which is dependent upon time, not distance. A very important factor in the determination of system accuracy is the fact that the results of the accuracy analysis do not include systematic compass errors. Depending upon what compass system is used, an error of from 1 to 5 per cent can be introduced into the present position information.

G. MAJOR FINDINGS:

The overall results of USAEPG testing indicated that all three systems performed with reasonable accuracy. The specific findings for each system were as follows:

1. Manufacturer A's systems exhibited better accuracy and reliabiltiy in comparison to the other two systems. However, it was found that A's systems contained several operational limitations (see Table 4), were more expensive than C's systems, but less expensive than B's system.

2. Manufacturer B's system did not meet four of the important Technical Requirements and it was the heaviest and most expensive of the tested systems.

3. Manufacturer C's systems contained several more design features not inherent in the other tested systems; namely, absolute altimeter capability; provisions of a continuous visual indication of bearing and distance to destination where the other tested systems "lock-up" at a distance of 1.5 nautical miles from destination; and hovering indications were more accurate due to the methods utilized to obtain the hover capability. In addition, Manufacturer C's systems were the least expensive.

H. CONCLUSIONS:

It is concluded that:

1. From analysis of engineering data, the ralative order of merit of each of the systems is as follows: Manufacturer C, Manufacturer A, and Manufacturer B.

2. Overall accuracy does not meet the requirements of the QMR.

3. Errors inherent in present heading reference systems are excessive.

I. RECOMMENDATIONS:

It is recommended that:

1. Future development of doppler navigation systems stress an increase in accuracy and elimination of errors presently inherent in heading reference systems.

2. Early production models of the selected system be sent to USAEPG for check test.

s/ G. D. ELLERSON
t/ G. D. ELLERSON
Colonel, Artillery
Deputy Commander

PART II. TEST PROGRAM

Three different doppler navigation systems, all operating in the Ke-band, were tested at the USAEPG. These systems were installed by the respective manufacturers in U. S. government furnished rotary- and fixed-wing aircraft.

The USAEPG test program was conducted in two phases, as follows: Phase I - bench tests, and Phase II - helicopter and fixed-wing flight tests.

Throughout all of the flight tests, the pilots utilized the doppler systems as the primary navigation aid.

PHASE I. BENCH TEST

A. Sensor Bench Tests

1. Purpose: To determine the mechanical and electrical characteristics of the doppler radar.

2. Criteria: Not applicable (N/A)

3. Method: The actual method used depended upon the test item. These procedures will not be documented here. All measurements were observed by U. S. Army personnel.

4. Results: The results of the radar bench test are listed below by manufacturer. Due to the differences in the equipments, some of the measurements are not directly comparable. These measurements serve mainly as a qualitative indication of the equipments' general condition at the time of test.

a. Manufacturer A

(1) Tracker acquires signal at 6 db S/N.

(2) Transmitter power output 1.65 watts

(3) Transmitter Frequency 13, 300 Mcs

(4) Transmitter spurious radiations - no obvious spurious radiations were detected.

b. Manufacturer B

(1) Receiver Sensitivity -91.5 dbm

(2) Receiver Bandwidth 1.26 Mcs

(3) Transmitter power output 17.8 watts

(4) Transmitter spurious radiations - no obvious spurious radiations were detected.

(5) Pitch gimbal limits stabilized $\pm 25^{o}$

(6) Azimuth gimbal limits $\pm 45^{o}$

(7) Transmitted Frequency 13,325 Mc $\pm$30 Mc

c. Manufacturer C

(1) Receiver - tracker sensitivity 0.13 μv

(2) Transmitter power output 0.275 watts

(3) Transmitter spurious radiations - no obvious spurious radiations were detected.

(4) Azimuth antenna limits $\pm 90^{o}$

(5) Transmitted Frequency 13,325 Mc $\pm$ 30 Mc

B. Computer-Display Bench Test

1. Purpose: To determine the capability of the computer to solve the navigational problem at any latitude, to measure the accuracy of the display.

2. Criteria: The system will provide the same accuracy regardless of the latitude of operation.

3. Method: The computer and display subsystems were placed in operation on the bench. A flight of 900 kilometers on a grid heading of 045 degrees was programmed with simulated ground speed signal of 150 knots, drift angle of 0 degrees, and heading

reference at 80 degrees North latitude applied to the computer.

4. Results: All equipments submitted for this evaluation utilize a flat earth approximation. All manufacturers systems rely upon accurate heading information from a compass system. In order to obtain the required accuracy at high latitudes the compass system would have to be compensated for earth's rate, coriolis acceleration, and meridian convergence.

C. Scale factors

1. Purpose: To determine the scale factors used in the system.

2. Criteria: N/A

3. Method: The scale factor of the various outputs were observed by U.S. Army personnel.

4. Results: The various outputs were observed on all equipments, all output devices were found to conform to the technical requirement (SCL-5953). The results of the V/H measurement are given below:

a. Manufacturer A: Accurate to within the specification.

b. Manufacturer B: Appears accurate to within the specification, however the scale factor and limits are not correct.

c. Manufacturer C: This manufacturer did not provide a V/H computer due to the lead time in obtaining a precision wound nonlinear potentiometer. However, complete provisions were made for this function within the confines of the navigation computer. It is anticipated that there will be a 6 to 8 ounce weight increase when the V/H computer parts are installed.

D. Maintenance:

1. Purpose: To obtain maximum information concerning reliability, maintainability, and related problem areas.

2. Criteria: N/A

3. Method: Total system operation time was recorded in permanent log books. All maintenance performed on the system was monitored and recorded in the log.

4. Results: All maintenance was performed by manufacturer personnel. No safety hazards were found on any of the test items. Running time and maintenance problem areas are shown below by manufacturer:

a. Manufacturer A.

(1) Doppler System No. 1

(a) Ground and airborne system checkout	1:00
(b) Bench tests	N/A
(c) Vulnerability tests	2:05
(d) Instrumented flight tests	27:50
(e) Compass swing	1:45
(f) Demonstrations	14:38
(g) Total time on test item	47:18

No apparent problems connected with this system. All bench tests on this manufacturer's equipments were performed on other systems.

(2) Doppler System No. 4

(a) Ground and airborne system checkout	10:08
(b) Bench tests	21:29
(c) Vulnerability tests	2:10
(d) Instrumented flight tests	30:36
(e) Compass swing	10:00
(f) Demonstrations	8:30

(g) Total time on test item 82:53

The manufacturer's representatives spent more time maintaining this equipment than their other system. This could be directly attributable to the fact that the antenna was accidentally bathed in hydraulic fluid during maintenance. An additional 3 hours were spent in removing the antenna from the aircraft and cleaning it - this time does not show in the above tabulation.

b. Manufacturer B

(1) Ground and Airborne System checkout 31:12

(2) Bench tests 11:45

(3) Vulnerability tests 2:00

(4) Instrumented flight tests 27:18

(5) Compass swing 1:55

(6) Demonstrations 1:00

(7) Total time on test item 75:10

Approximately 8 hours was spent by the manufacturer's representatives in repairing the sensor portion of the doppler system. The remainder of the recorded time was spent in repairing and aligning the computer. Quite a bit of trouble was caused by the failure of two relays in the computer.

c. Manufacturer C

(1) Doppler System No. 3

(a) Ground and Airborne System checkout 33:55

(b) Bench tests (for data collection) 13:10

(c) Vulnerability tests 3:00

(d) Instrumented flight tests 21:09

(e) Compass swings	3:00
(f) Demonstrations	10:10
(g) Total time on test item	84:24

Of the 33:55 spent by the manufacturer in maintaining his system, 16:10 was spent in the initial checkout and isolation of an intermittent problem. Another 10:05 was spent in trying to isolate a problem with the memory operation; eventually the AGC circuit board was replaced. Another 3:15 was spent in removing the system from the aircraft and replacing the system in the aircraft.

(2) Doppler System No. 5

(a) Ground and Airborne System checkout	11:45
(b) Bench tests (for data collection)	:45
(c) Vulnerability tests	2:10
(d) Instrumented flight tests	18:03
(e) Compass swings	7:55
(f) Demonstrations	1:55
(g) Total time on test item	42:33

Approximately 9 hours were spent by the manufacturer's representatives trying to correct problems connected with the hovering operation of the system. During the last instrumented flight the inverter supplying power to the doppler got very hot and started smoking. Thus at least 6 hours of maintenance time could be directly attributed to the inverter as the cause. One-half hour was spent in correcting a mechanical lockup in the computer.

PHASE II. HELICOPTER AND FIXED-WING FLIGHT TESTS FOR LONG TERM ACCURACIES

1. Purpose: To determine the long term doppler system navigational accuracy.

2. Criteria: Contained in SCTR SCL-5953 classified Confidential.

3. Method:

a. General: Each OV-1 aircraft was flown approximately 12 hours over various paths at absolute altitudes between 2,000 ft and 14,000 ft.

Each UH-19 aircraft was flown approximately 13 hours over various paths at absolute altitudes between 1500 and 3000 ft.

The doppler was used as a prime navigation aid. The pilot used pre-selected destinations as doppler inputs and flew the doppler readouts around closed courses. Doppler and heading reference outputs were telemetered to the ground, and compared with FPS-16 ground track radar information.

b. Data Collection.

(1) Dopplers: The following doppler and heading reference information was converted to Binary-Coded-Decimal form in the aircraft and telemetered to the ground at 1 sec intervals:

(a) N-S position (0.1 nm)

(b) E-W position (0.1 nm)

(c) Ground speed (0.1 kt)

(d) Drift angle (0.1 degree)

(e) Heading reference (0.1 degree)

(f) Bearing to destination (0.1 degree)

(g) True Air Speed (0.1 kt)

(2) Ground track (FPS-16)

The space position of the aircraft was recorded at 0.1 second intervals in terms of range, azimuth, and elevation. This data was corrected for refractive index, translated and rotated to a N-S and E-W coordinate system tangent to the earth at the point used as a visual

starting point by the pilots. The ground speed was computed by taking the first derivative of the second-degree least-squares curve fitted to the position data. The velocity direction (track direction) is the tangent to this curve at a given point. Parameters computed from ground track information were:

(a) N-S position

(b) E-W position

(c) Ground speed

(d) Velocity direction

(e) Total distance traveled (from any point)

(3) General - Parameters listed above for both doppler and ground track were tabulated at 10 second intervals for all flights.

c. Discussion of Theory of Doppler Position Errors: A doppler system may be broken down into the following components.

(1) Radar and velocity computers

(2) Heading reference and magnetic variation input

(3) Position computer

(4) Present position display

The radar/velocity component provides the position computer with 2 horizontal components of velocity referenced to the aircraft. These may be provided as Velocity Along heading (V_h) and Velocity Across Heading (V_d) or Ground Speed (V_g) and Drift Angle (δ). The heading reference and magnetic variation inputs to the position computer orient the velocity components relative to the ground.

The position computer continuously integrates the velocity components in N-S and E-W directions and thereby computes the present position relative to the starting point.

The Present Position (PP) error is therefore a composite of (1) velocity errors; (2) computer errors; and (3) heading reference and

magnetic variation errors (compass errors). If the PP errors are resolved about the aircraft track direction the resulting component errors are functions of the above errors (for angular errors of 2° or less) as follows:

Long-Track (ΔR) = f(ΔV_g, Δ computer)

Cross-Track (ΔT) = f($\Delta \delta$, Δ compass, Δ computer)

d. Analysis of Data. For the purposes of this evaluation it was necessary to eliminate systematic compass errors and systematic velocity and/or computer errors. It is assumed that these are calibration errors and are not representative of the system's potential performance.

Each leg of a flight was considered separately. The start of each leg was defined to have zero position error. At each data point (1 point/10 sec) the error was resolved about the ground radar determined track direction into long and cross track errors.

These errors were expressed as percent of distance traveled:

Error X 100/Distance Traveled

This method of expressing the errors is convenient since constant angular errors result in constant percent cross-track errors:

SIN (Δ(Angle)) = ΔT/Distance

and systematic velocity errors or computer errors (assuming constant velocity) Result in constant ΔT/Dist and ΔR/Dist.

Identical samples were considered for each system. Points at distances of 25 to 150 kms were used.

For long-track error all points were considered to be from the same population. The calculated mean is assumed the calibration error and deviations about this mean are considered to be system variability.

For cross-track error, all points along the same heading ($\pm 3^{\circ}$) are considered to be from the same population and their mean is assumed to be the compass error (for that heading) and calibration errors.

The variability about this mean is assumed to be a composite of doppler error, random compass error, and small magnetic variation changes.

4. Results.

A sample of 30 points was selected for each system. This sample was selected to be representative of the system's over-all performance and the same number of distances and headings were used for each system. From the data, the along and across track estimated standard deviations were calculated. These standard deviations were corrected for estimated random errors caused by data collection, as follows:

S^2 system $+S^2$ radar $+S^2$ telemetry = S^2 data

Assuming a maximum error caused by the composite of radar and telemetry of 0.2 km and applying this error to the average distance of 50 km:

Maximum error in % of distance = .4%

Assuming a normal distribution:

$S = .4\%/2.5 = 0.16$

$S^2 = .03$

This value was subtracted from the S^2 found from the data.

At a 95% confidence level, the 90% tolerance limits are considered the "maximum error" and the 50% tolerance limits are considered the "probable error". A summary of the results is given below:

TABLE 5

Results of Accuracy Analysis

Errors	System No. Fixed-Wing			Helicopter	
	1	2	3	4	5
A. Along Track Error X 100/ Distance Traveled					
"Maximum Error"	.64	1.25	1.12	1.22	1.40
"Probable Error"	.33	.65	.58	.72	.82
Mean (Suppressed)	0.0	0.0	0.0	0.0	0.0
Estimated Standard Deviation	.25	.49	.44	.48	.55
Number of Points	30	30	30	30	30
B. Across Track Error X 100/ Distance Traveled					
"Maximum Error"	.51	.74	1.07	.79	2.27
"Probable Error"	.26	.38	.55	.46	1.33
Mean (Suppressed)	0.0	0.0	0.0	0.0	0.0
Estimated Standard Deviation	.20	.29	.42	.31	.89
Number of Points	30	30	30	30	30

APPENDIX B

DETERMINATION OF DATA FOR

PROGRAMMING DOPPLER COMPUTERS

1. Map Data.

a. North-south and east-west values required for programming the Doppler navigation computer may be determined from a map by the following procedures (reference figure 35):

(1) Locate the terminal points of the flight path.

(2) Draw a true north-south line through one point and a true east-west line through the second point so that they intersect.

(3) Measure the north-south and east-west distance from base (point 1) to destination (point 2) along these lines.

b. Accuracy of the values obtained by this method are dependent upon the scale and quality of the map used and on the care taken in making the measurements.

2. Computed Data from Latitude and Longitude. North-south and east-west data can also be determined from latitude and longitude information by the following process:

a. From a source such as US Coast and Geodetic Survey publications or other reliable publications, determine the latitude and longitude of the base (point 1) and destination (point 2).

Example: Base - Cairns AAF 31° 16' 05" N
85° 43' 36" W

Destination - Crestview VOR 30° 49' 33.4" N
86° 40' 45" W

b. To determine the north-south distance from base to destination, subtract latitudes and convert directly to nautical miles or kilometers.

Note: One minute of latitude equals 1 nautical mile.

31°	16'	05.0"
30°	49'	33.4"
	26'	31.6"

26' 31.6" = 26.5 nautical miles = 49.16 kilometers.

c. To determine the east-west distance from base to destination, subtract longitudes.

86°	40'	45"	*57' 09" = 57.15 n.m. at equator*
85°	43'	36"	
	57'	09"	

Since the lines of longitude converge at the poles, this is not the true east-west distance and must be corrected by multiplying by the cosine of the mid-latitude.

d. Determine the mid-latitude cosine.

(1)

31°	16'	05.0"
30°	49'	33.4"
	26'	31.6"

(2)

```
  13' 15.8"
2/26' 31.6"
  2
  6
  6
    3
    2
    11
    10
     16
     16
```

(3)

30°	49'	33.4"
	13'	15.8"
31°	02'	49.2"

(4) From trigonometric tables - Cosine $31^{\circ} 02' 49.2'' =$ .856749.

e. East-west distance is therefore 57.15 x .856749 = 48.96 n. m. = 90.74 kilometers.

f. Since Crestview is southwest of Cairns, the values 26.5 n. m. south (49.16 kilometers) and 48.96 n. m. west (90.74 kilometers) would be inserted in the navigation computer as the desired destination.

3. Determination of Variation. Variation for insertion into the navigation computer is determined directly from the available maps. For short flights over areas of little variation change, an average variation can be determined by inspection of the map. For longer flights or for flights over areas of erratic variation change, the flight should be broken into shorter legs and the variation determined for each leg. These values are then inserted into the computer as the flight progresses. (See figure 36.) If an approach or any significant flying is to be done at the terminal area, the variation of the terminal area should be inserted at the destination in order to prevent the introduction of unnecessary errors.

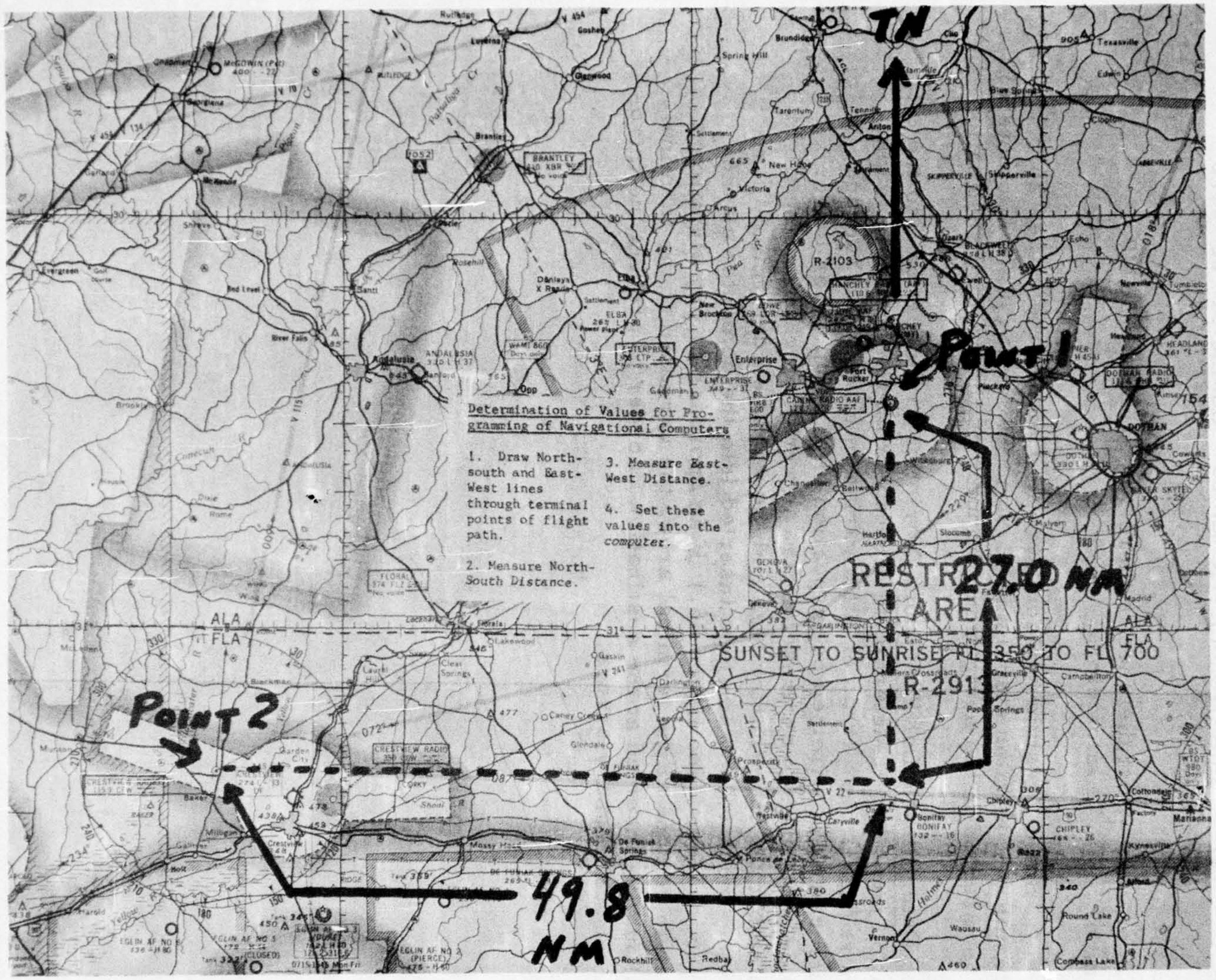


Figure 35. Determination of valves for programming navigational computers.

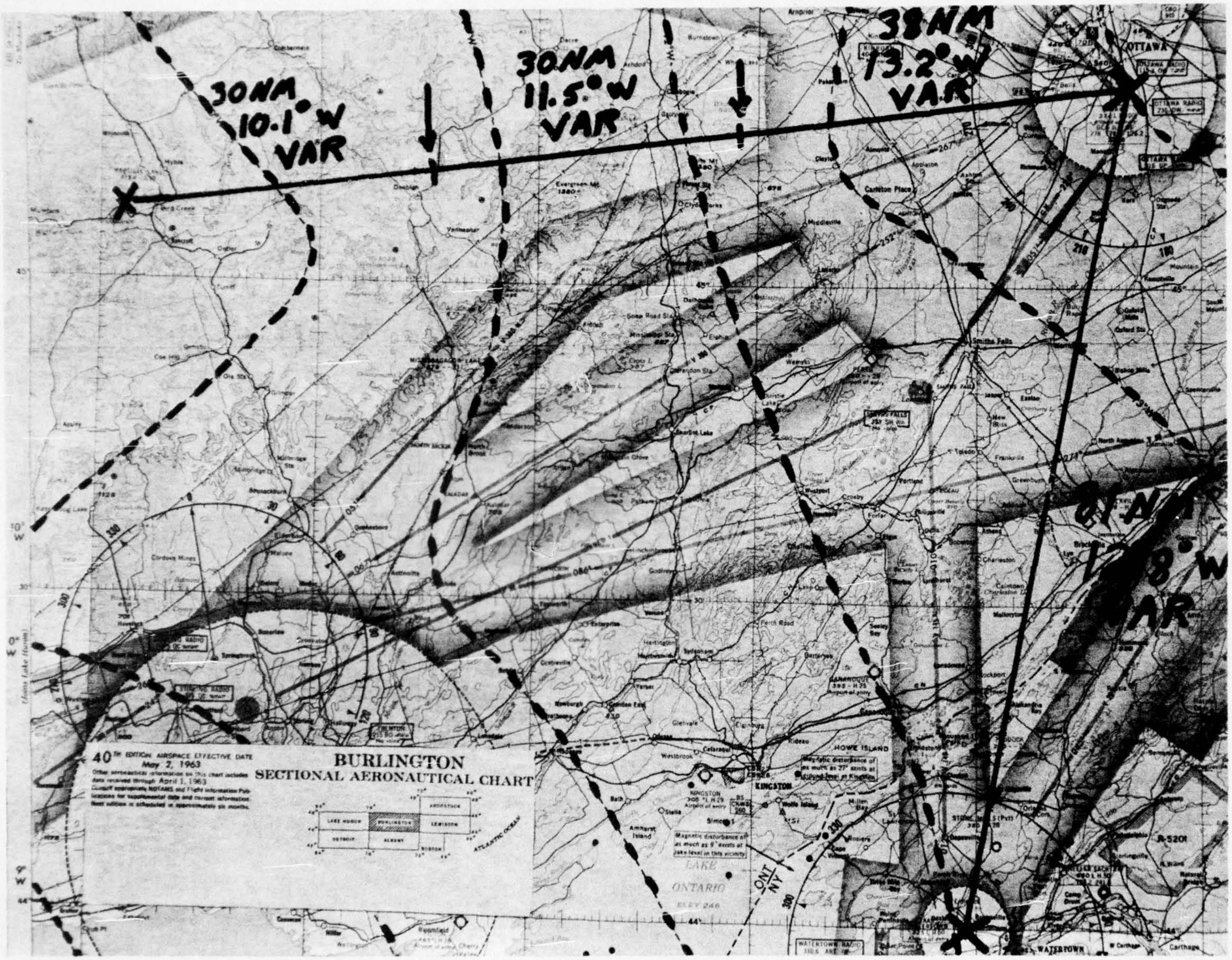


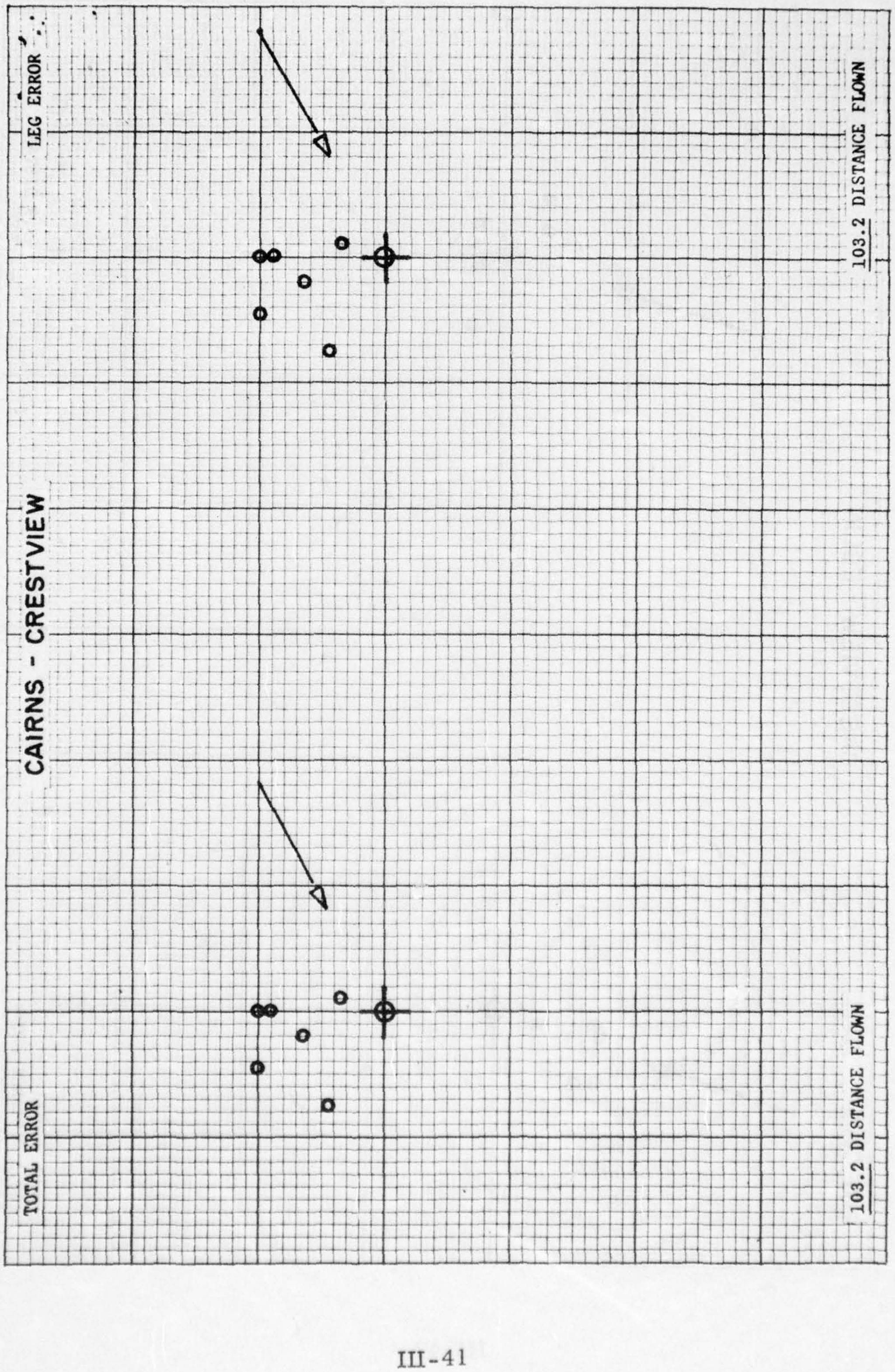
Figure 36. Determination of magnetic variation valves for programming navigational computers.

APPENDIX C

Doppler A(FW) Position Error

The data recorded in appendix G has been plotted on graphs to provide an immediately available readout of the Doppler navigation system leg error and total position error. These plots represent total system error. This data should not be used for direct comparison purposes without detailed analysis.

Graph Scale: One Inch = Two Kilometers


CAIRNS - CRESTVIEW
LEG ERROR
103.2 DISTANCE FLOWN
TOTAL ERROR
103.2 DISTANCE FLOWN

AD-A031 912 ARMY AVIATION TEST BOARD FORT RUCKER ALA F/G 17/7
MILITARY POTENTIAL TEST (COMPARATIVE EVALUATION) OF DOPPLER NAV--ETC(U)
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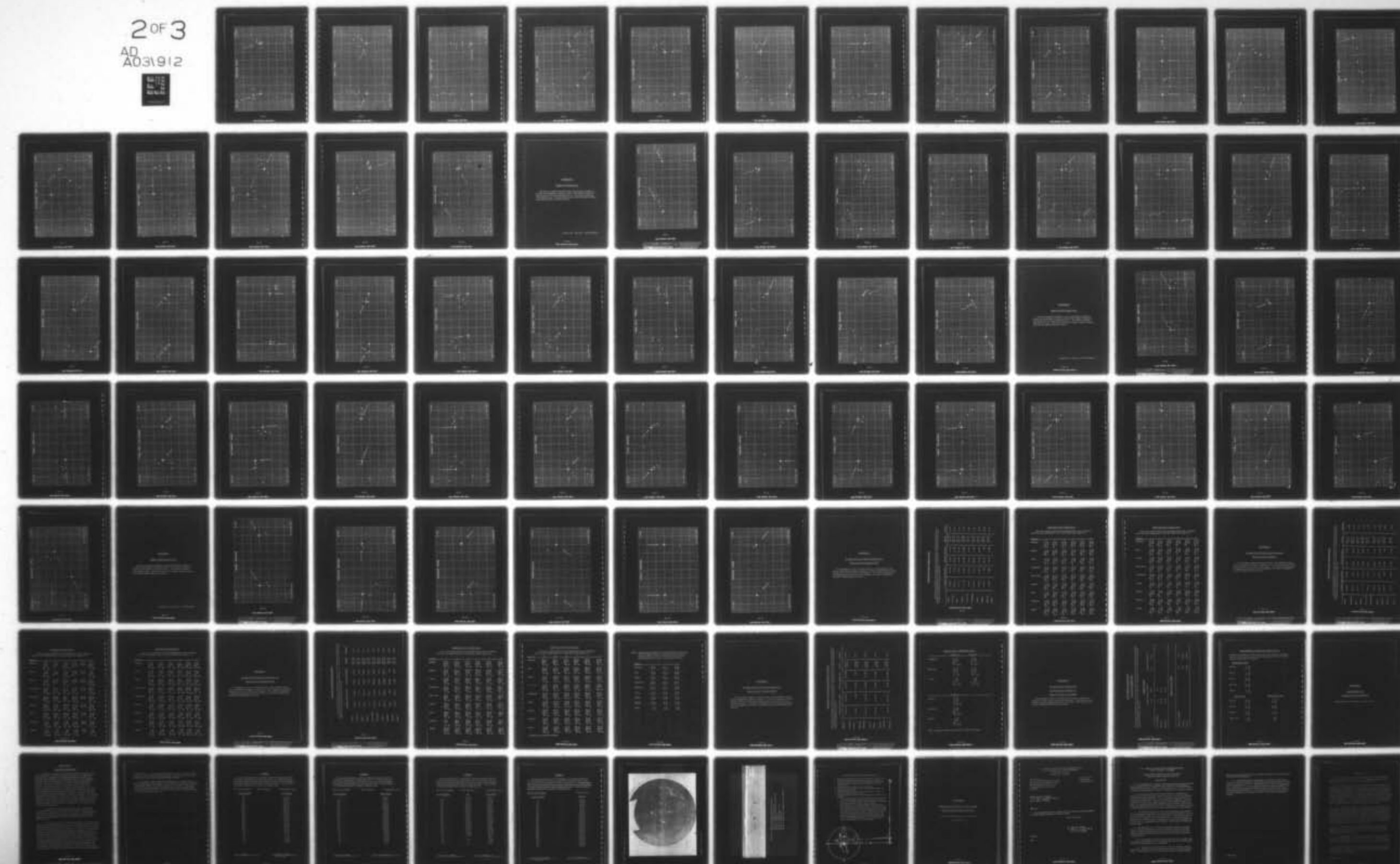
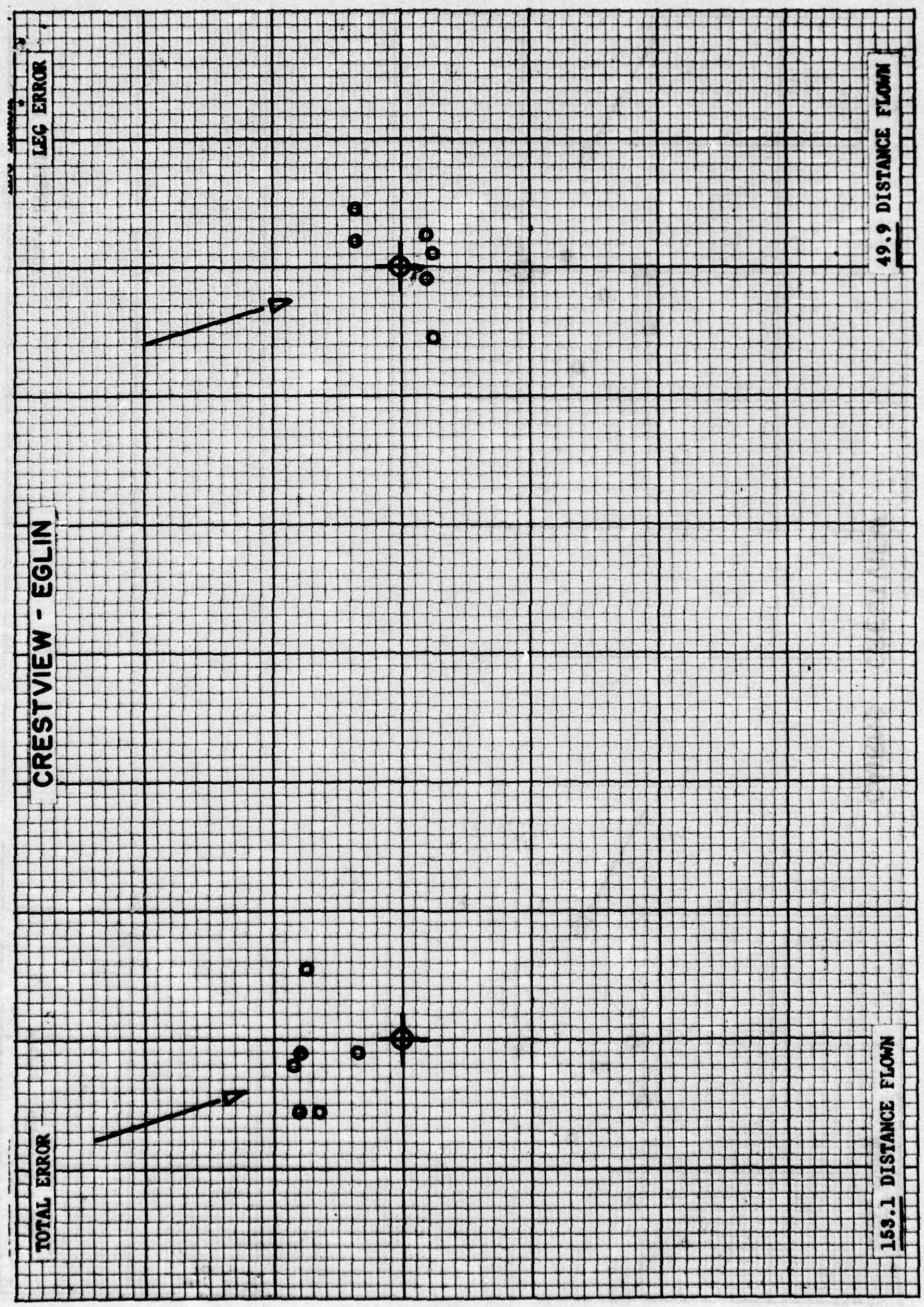
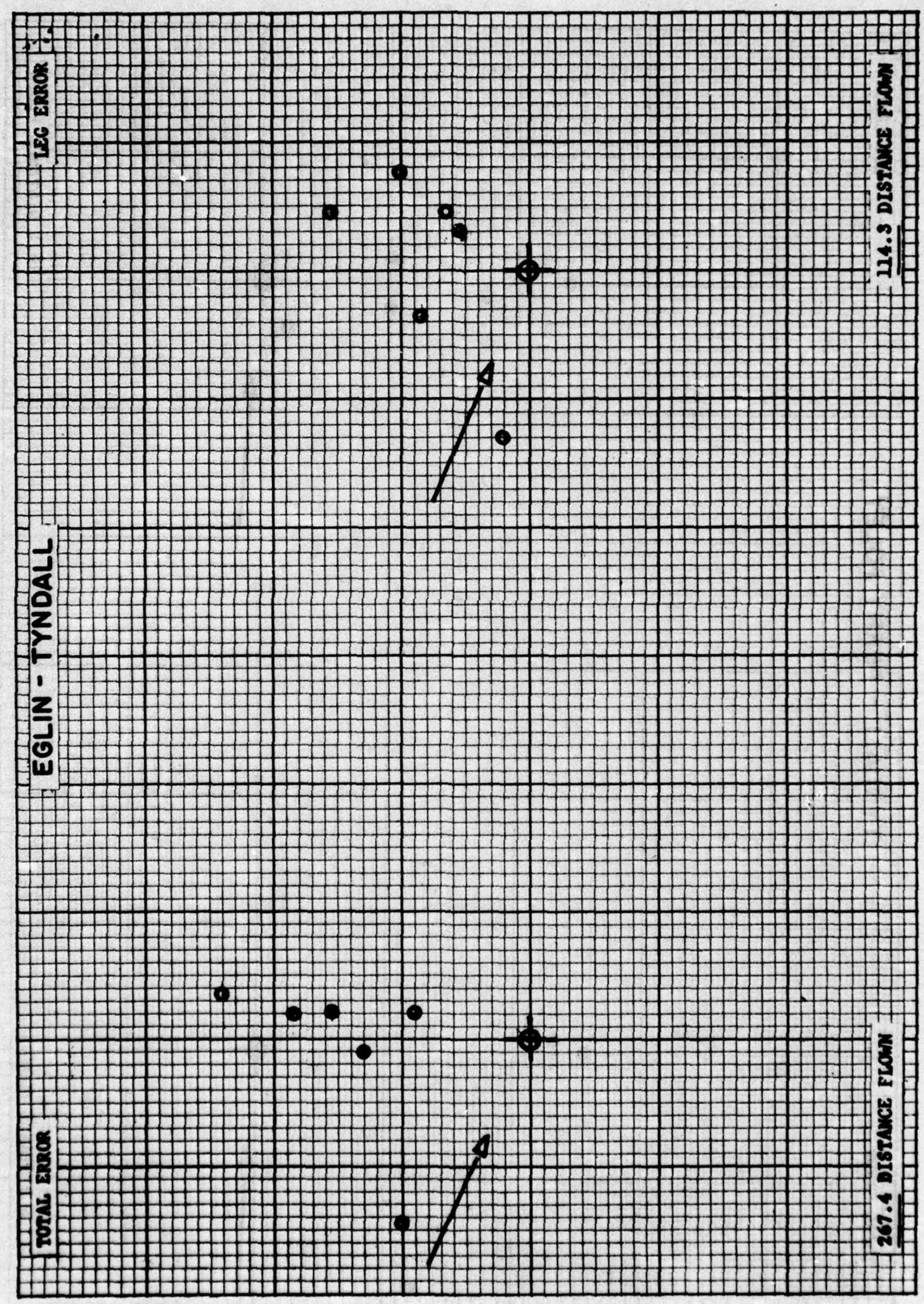
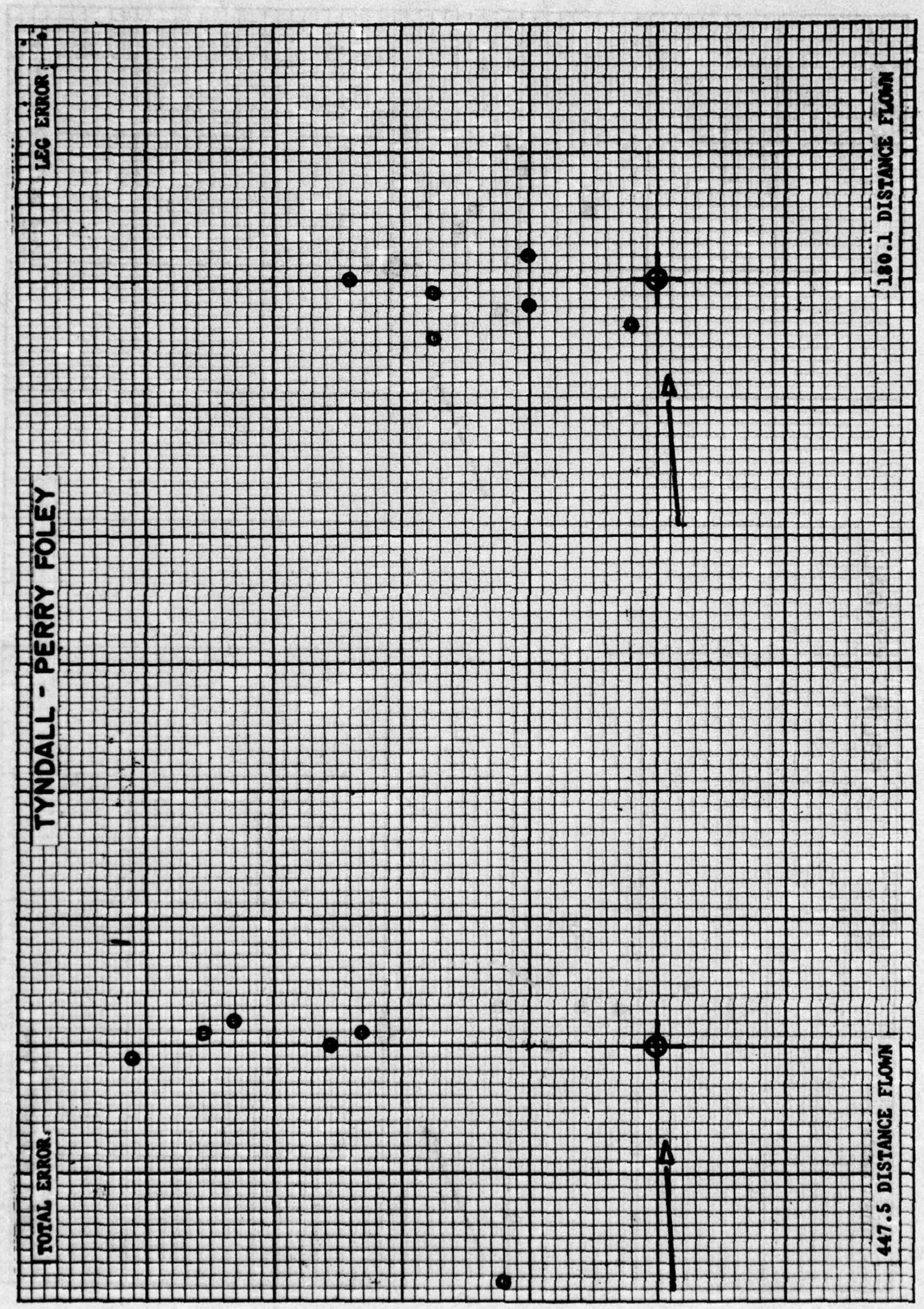
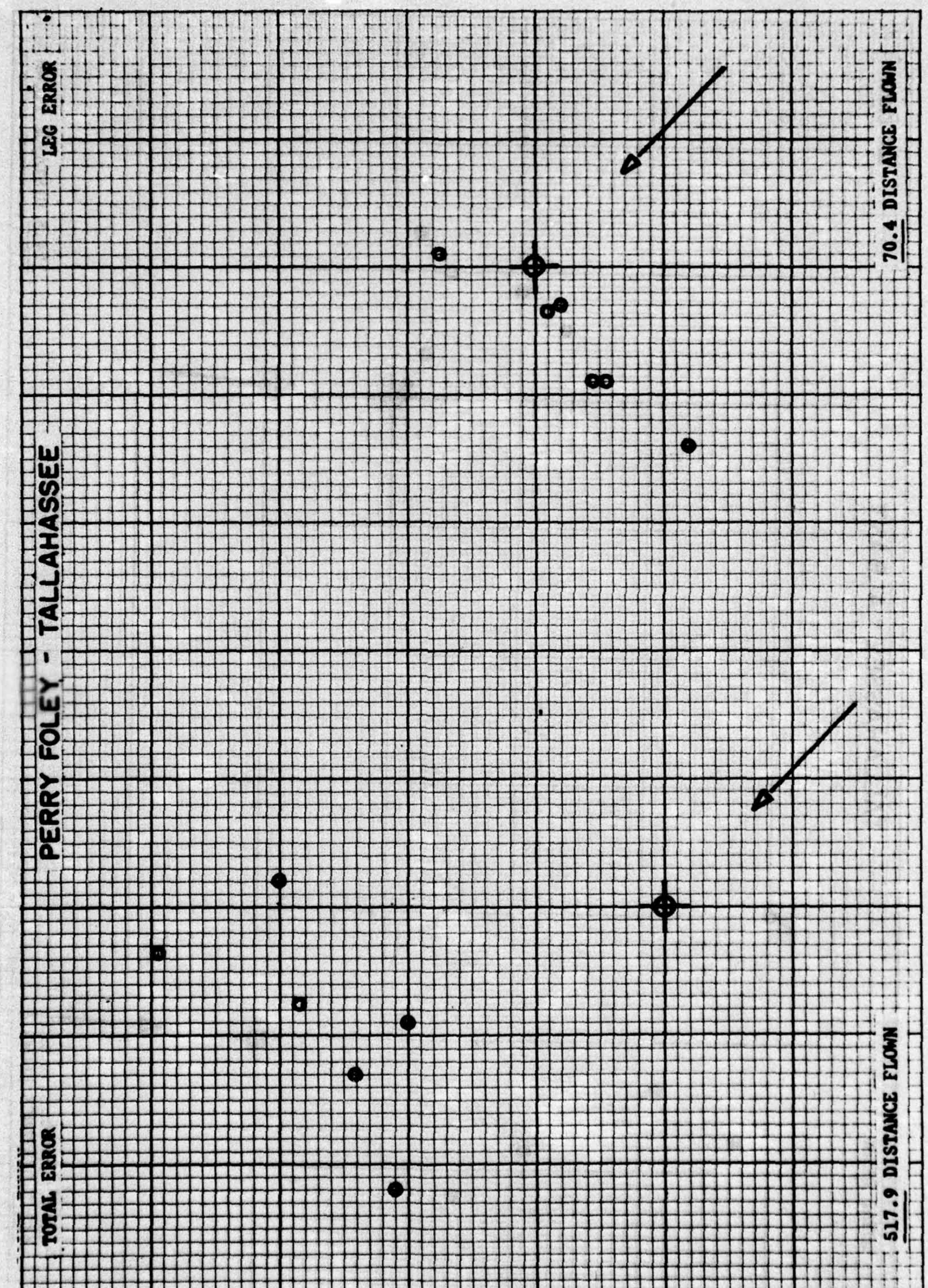
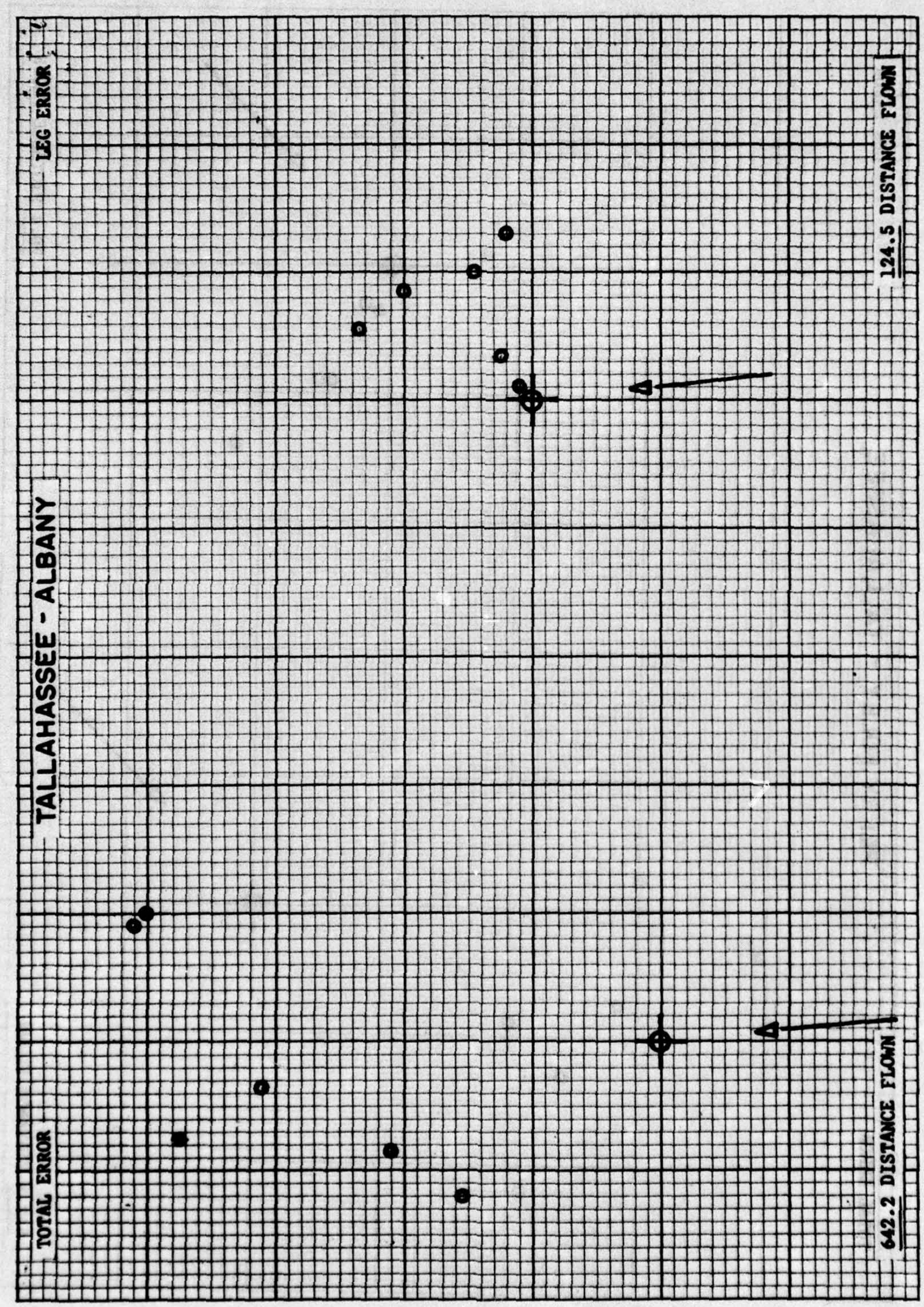


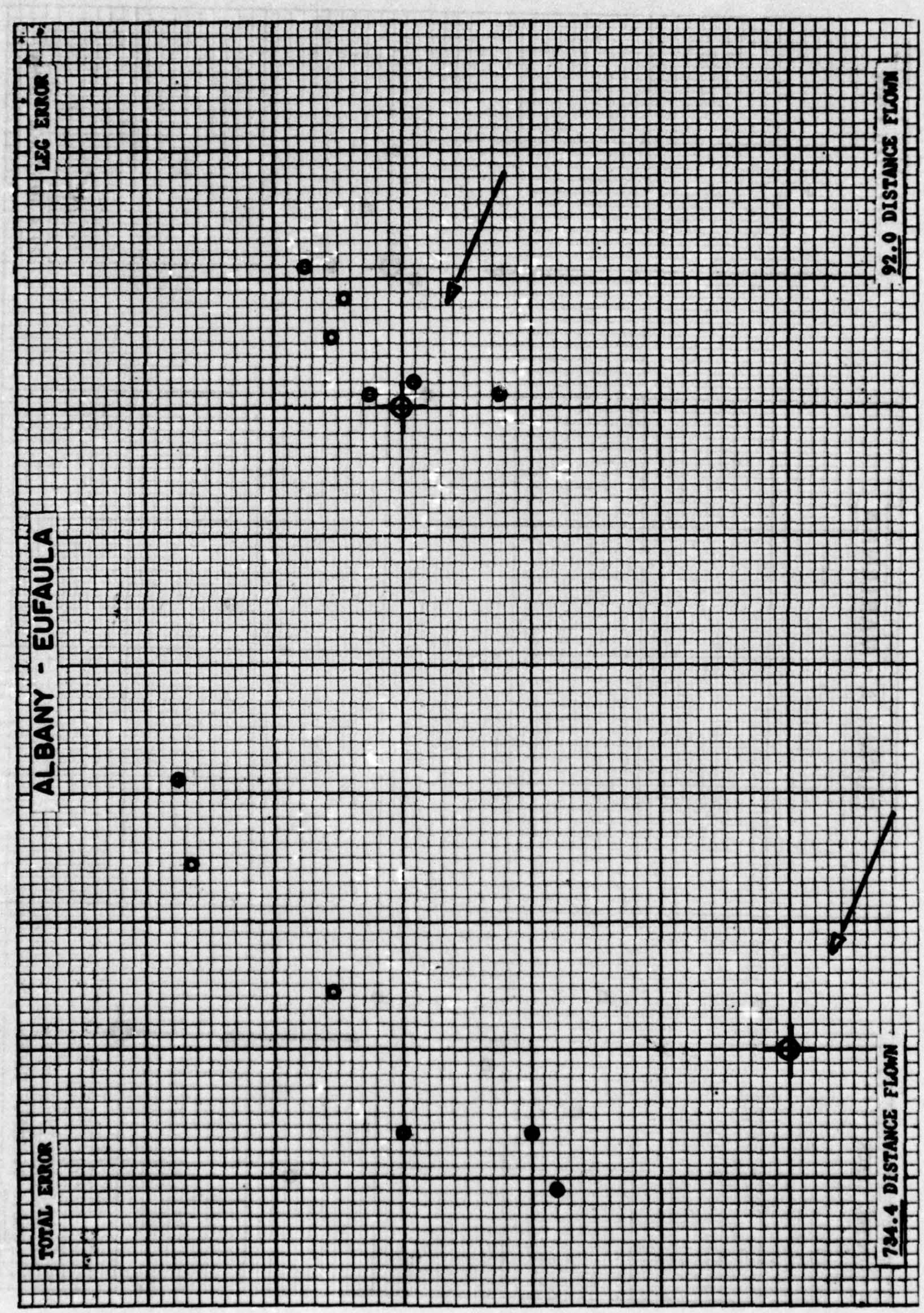

LEG ERROR
CRESTVIEW - EGLIN
49.9 DISTANCE FLOWN
TOTAL ERROR
153.1 DISTANCE FLOWN


EGLIN - TYNDALL
LEG ERROR
114.3 DISTANCE FLOWN
TOTAL ERROR
267.4 DISTANCE FLOWN


TYNDALL - PERRY FOLEY
LEG ERROR
180.1 DISTANCE FLOWN
TOTAL ERROR
447.5 DISTANCE FLOWN


PERRY FOLEY - TALLAHASSEE
LEG ERROR
TOTAL ERROR
70.4 DISTANCE FLOWN
517.9 DISTANCE FLOWN


TALLAHASSEE - ALBANY
LEG ERROR
124.5 DISTANCE FLOWN
TOTAL ERROR
642.2 DISTANCE FLOWN



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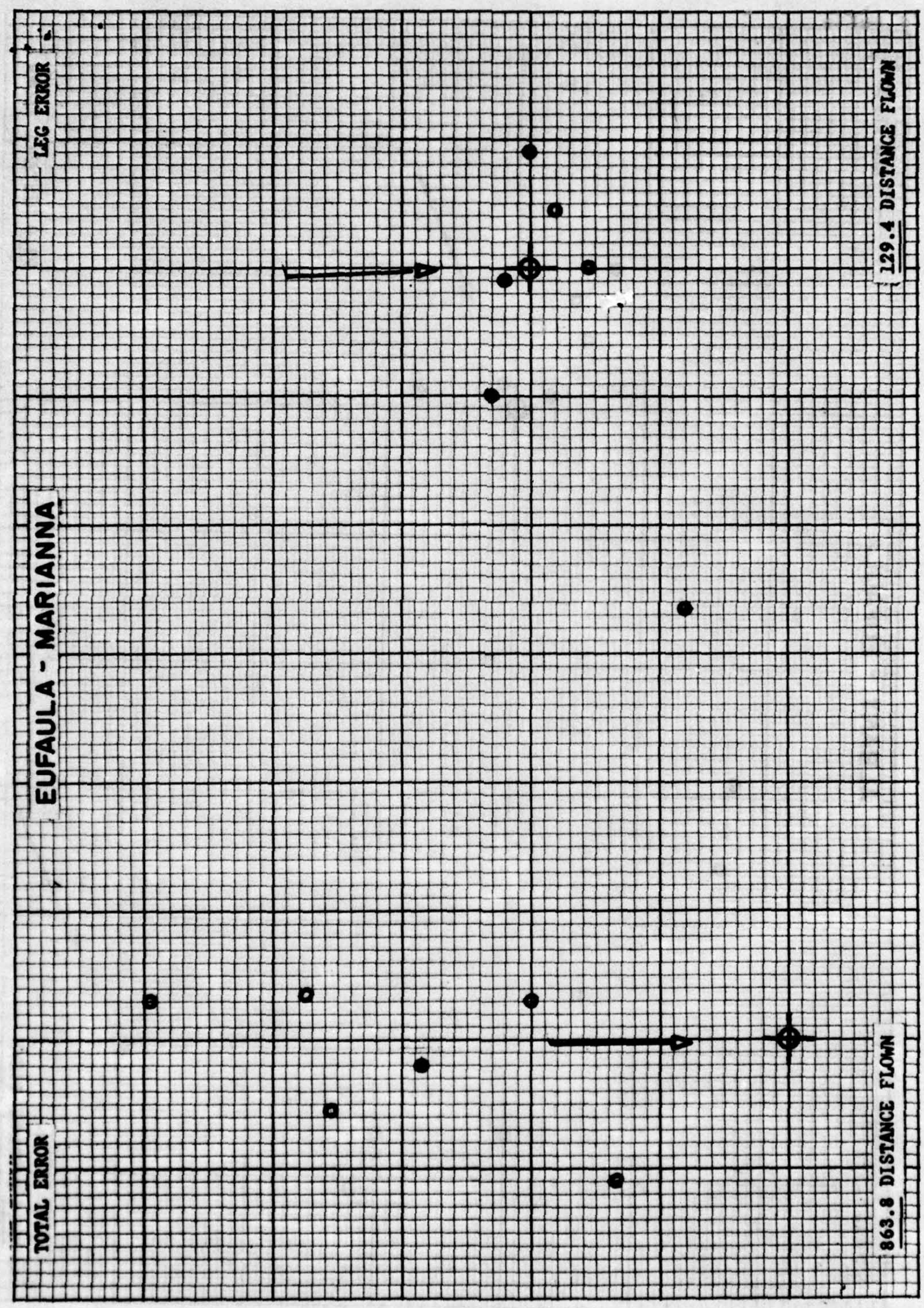
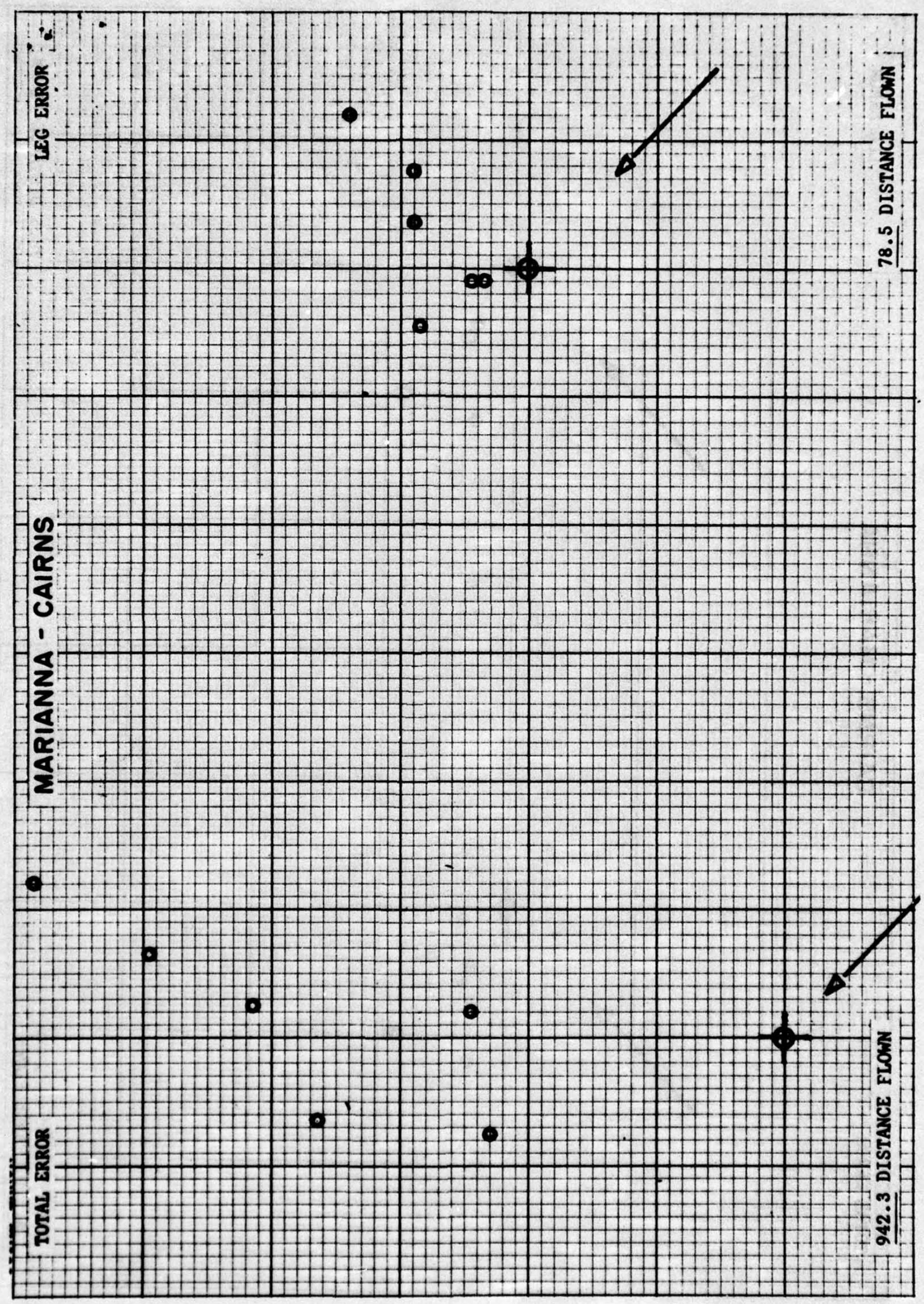
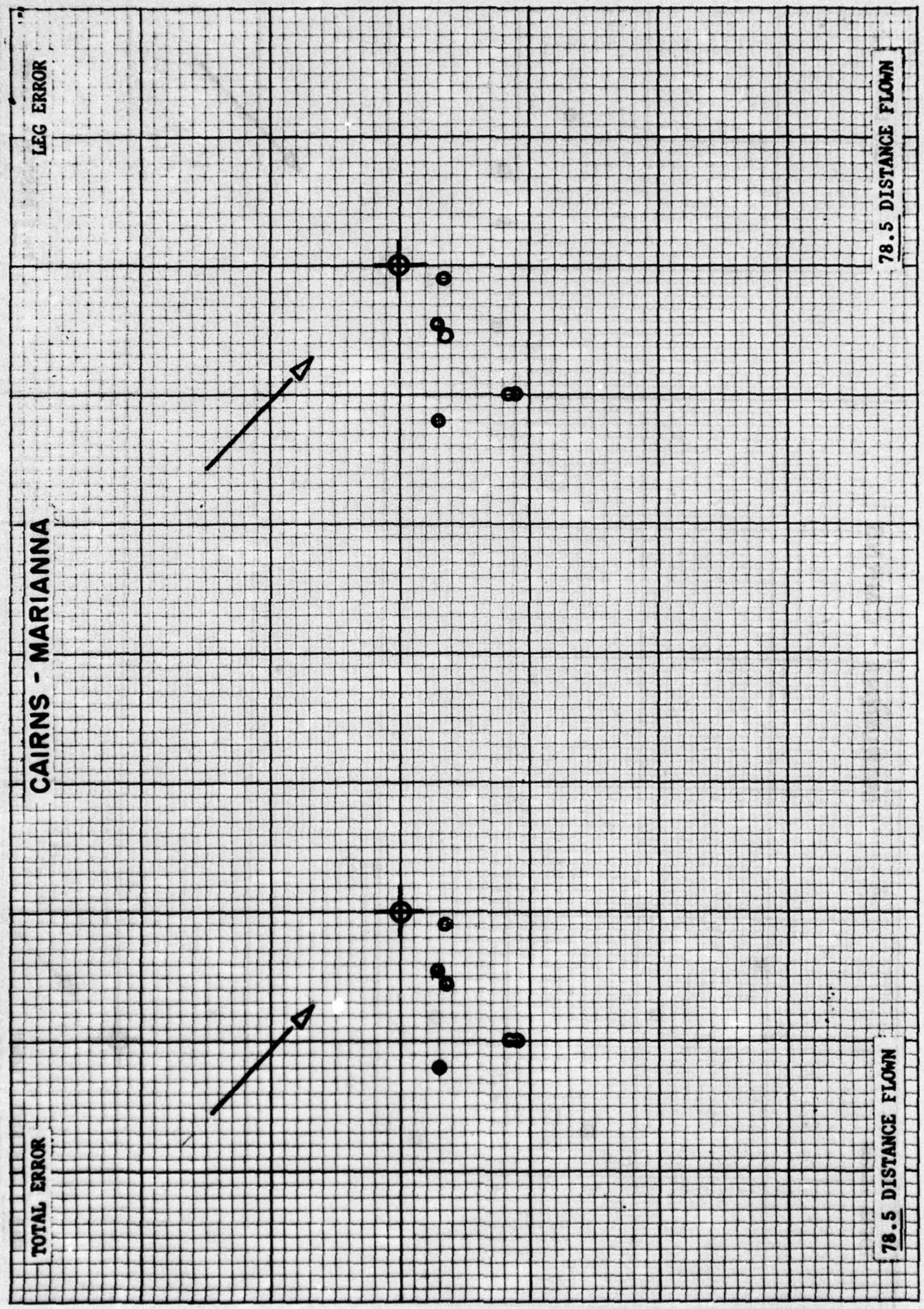
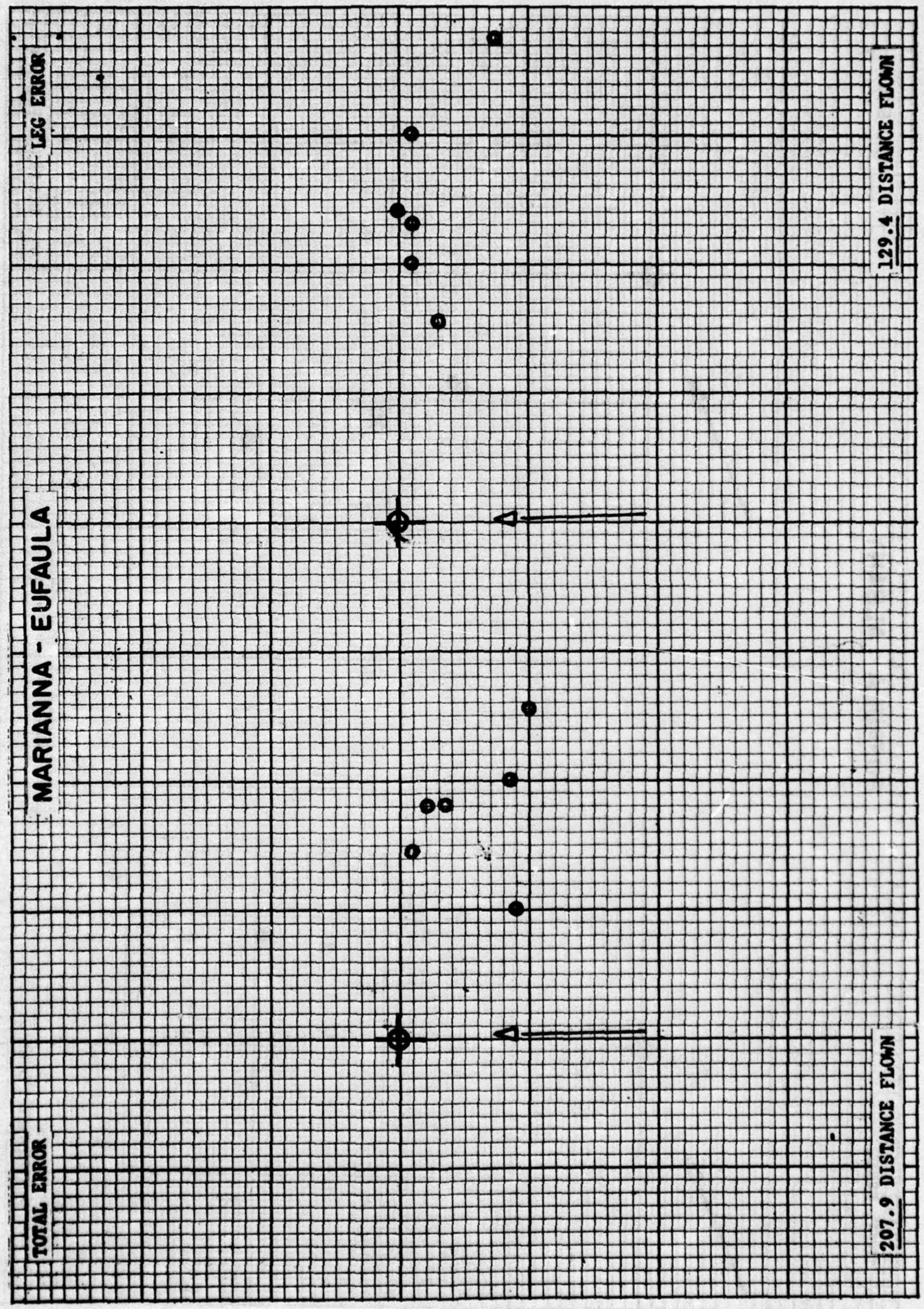
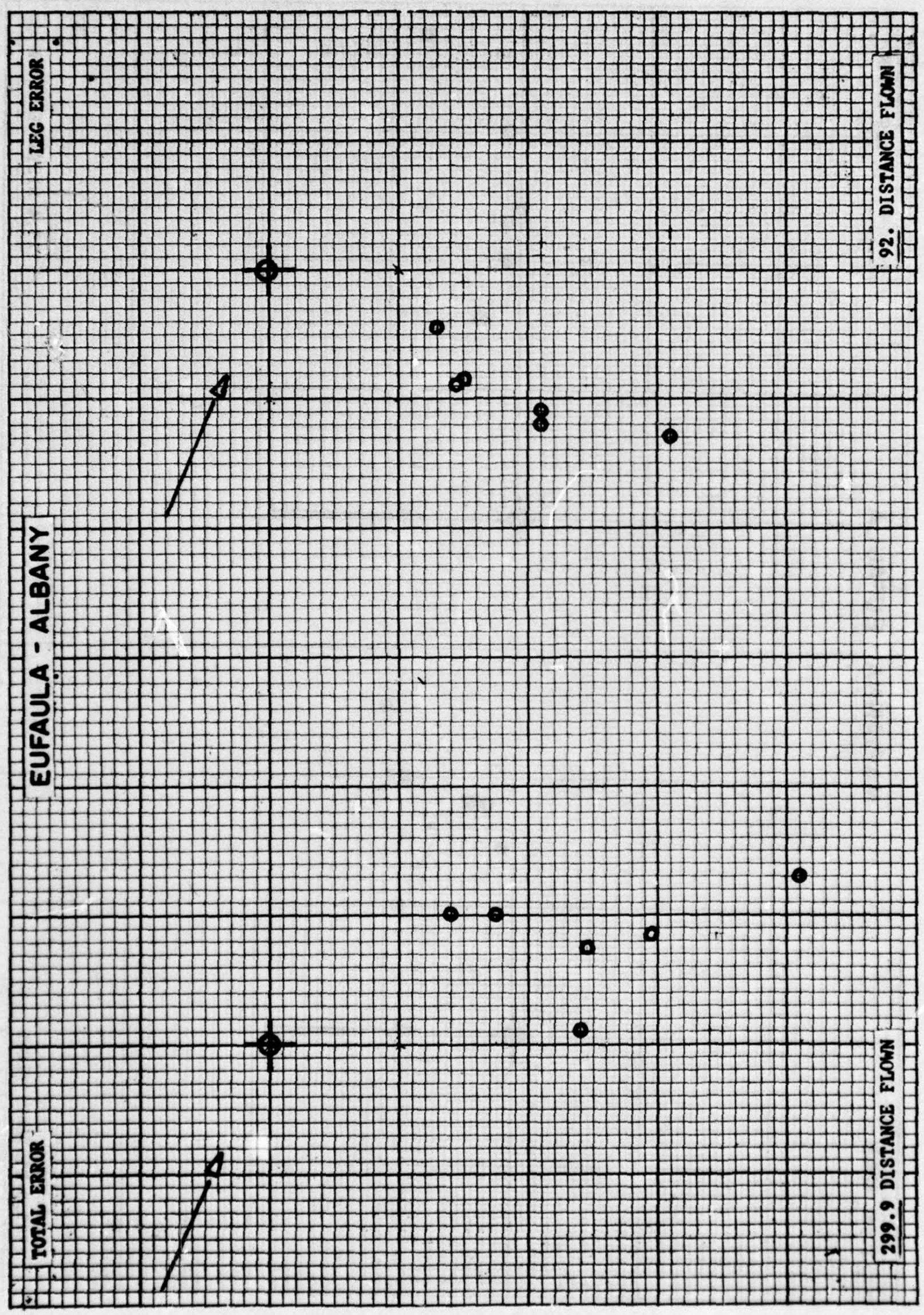
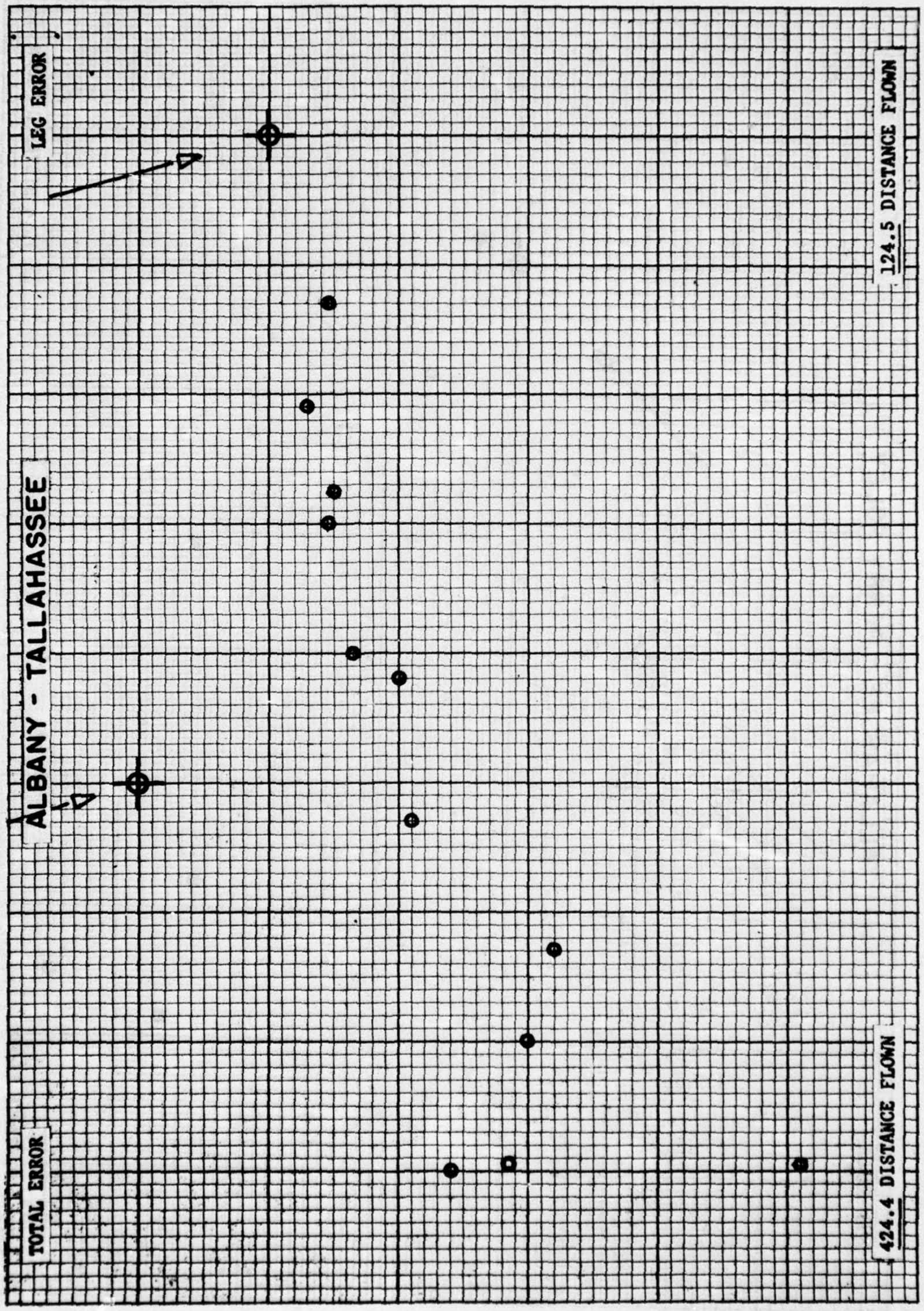

EUFAULA - MARIANNA
LEG ERROR
129.4 DISTANCE FLOWN
TOTAL ERROR
863.8 DISTANCE FLOWN


MARIANNA - CAIRNS
LEG ERROR
TOTAL ERROR
78.5 DISTANCE FLOWN
942.3 DISTANCE FLOWN


CAIRNS - MARIANNA
LEG ERROR
78.5 DISTANCE FLOWN
TOTAL ERROR
78.5 DISTANCE FLOWN


MARIANNA - EUFAULA
LEG ERROR
129.4 DISTANCE FLOWN
TOTAL ERROR
207.9 DISTANCE FLOWN


EUFAULA - ALBANY
LEG ERROR
92. DISTANCE FLOWN
TOTAL ERROR
299.9 DISTANCE FLOWN



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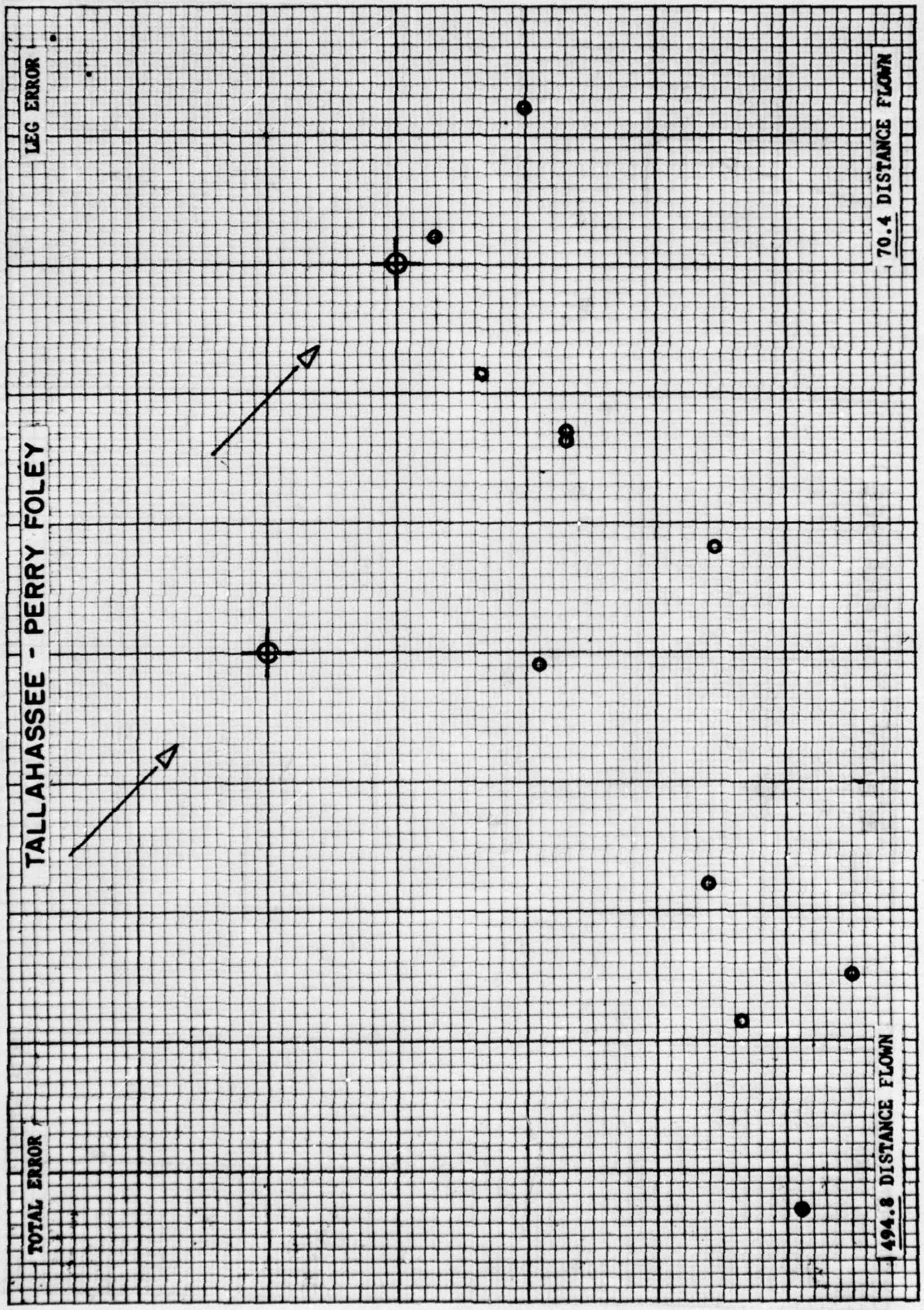
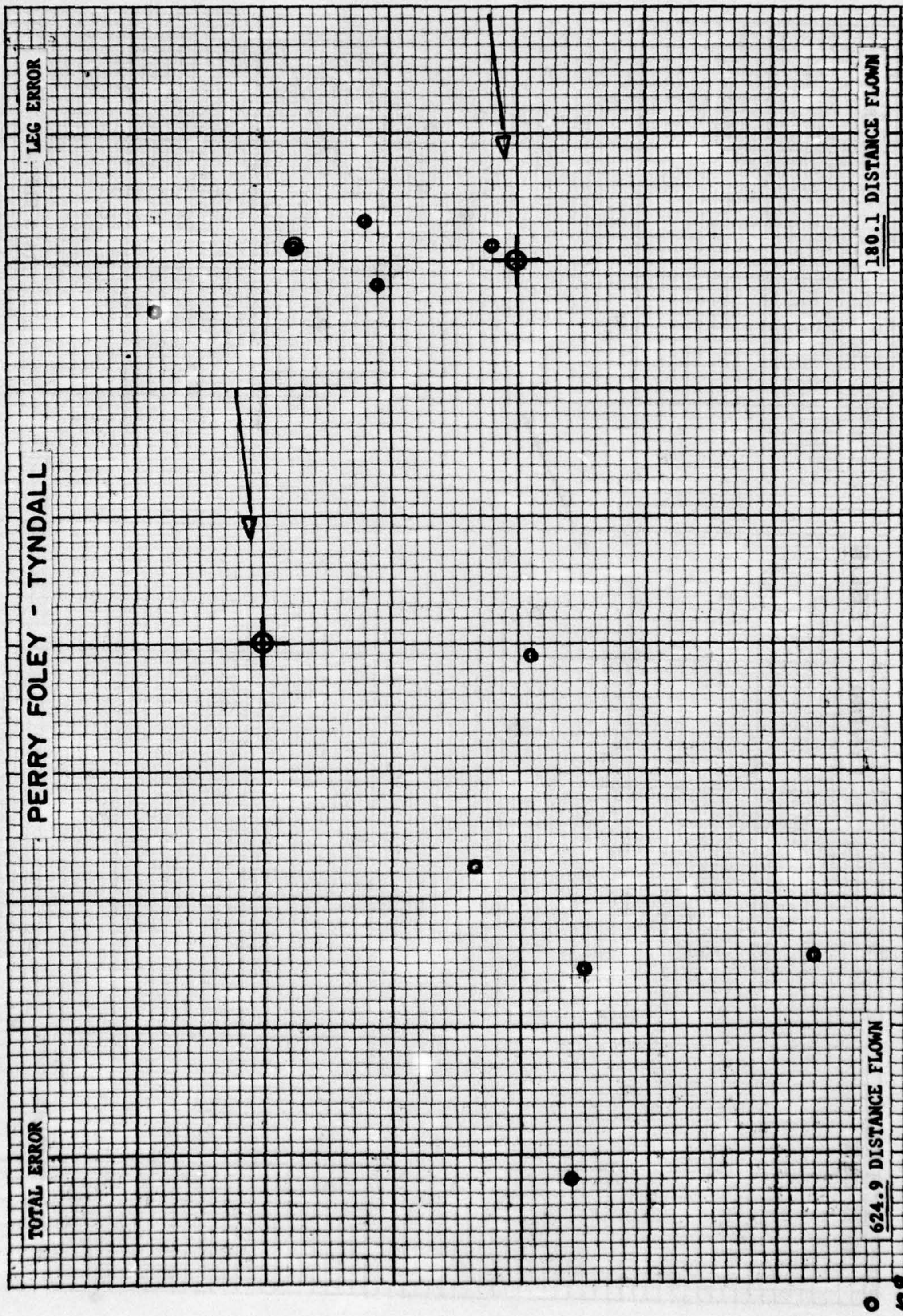
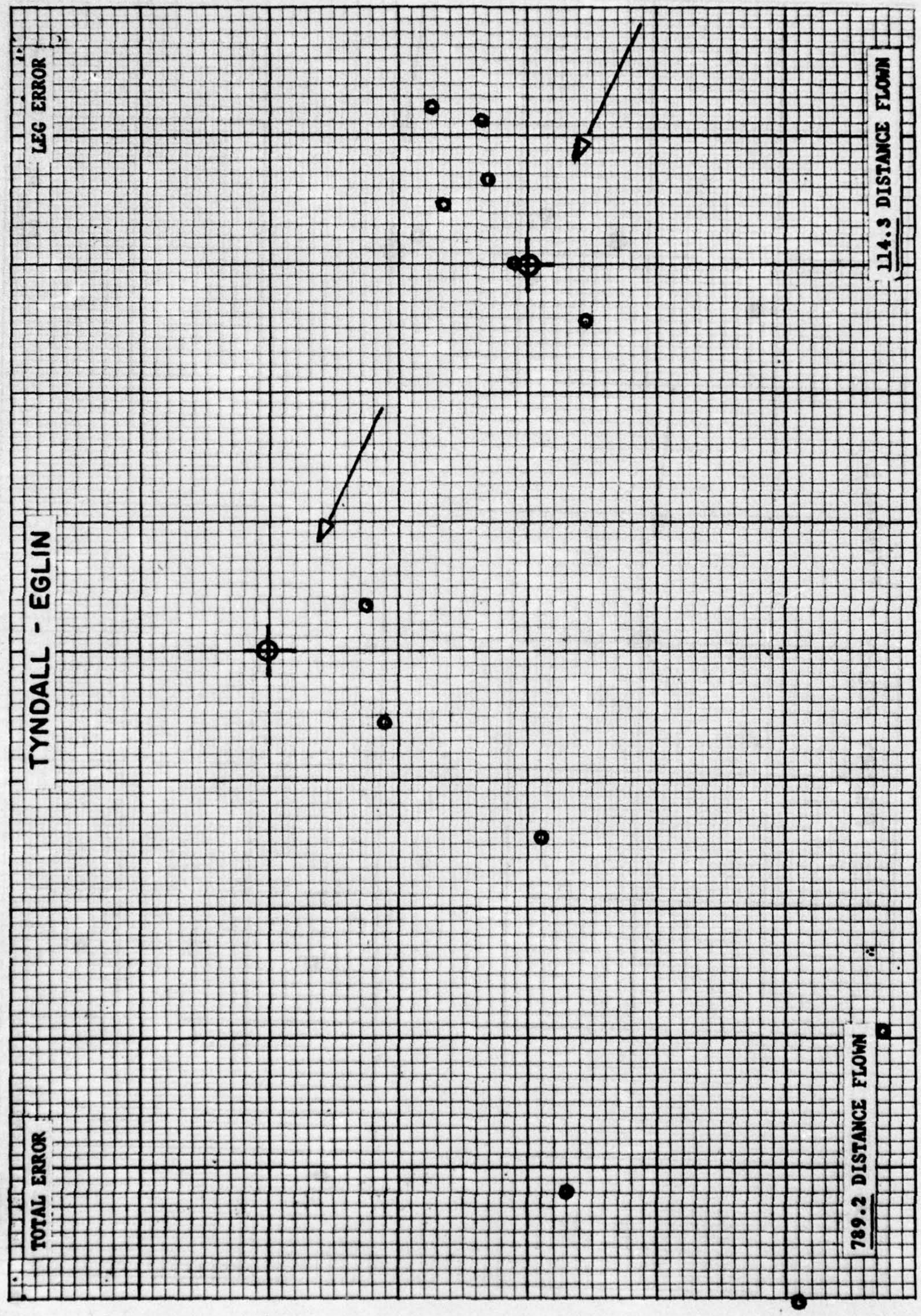
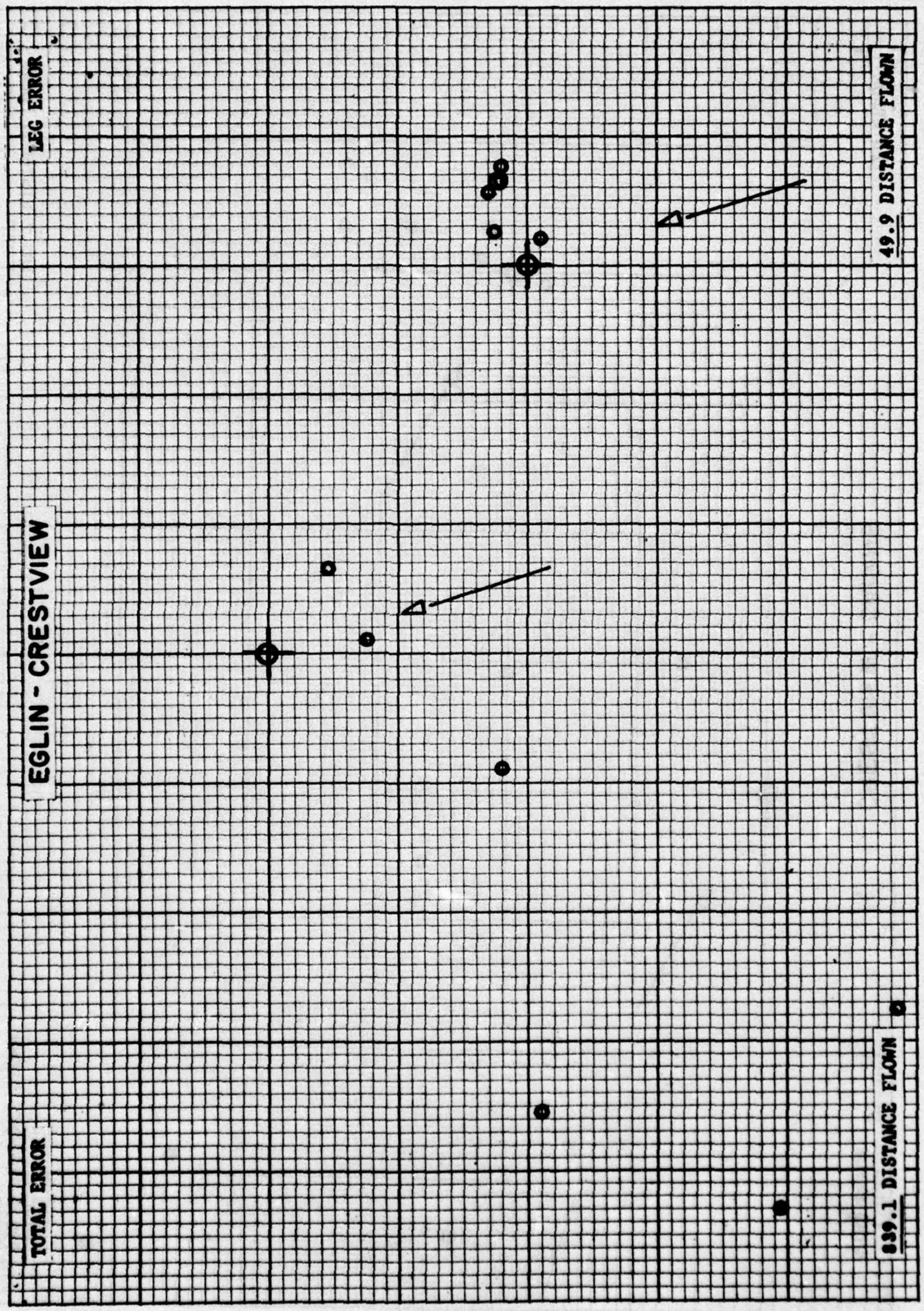
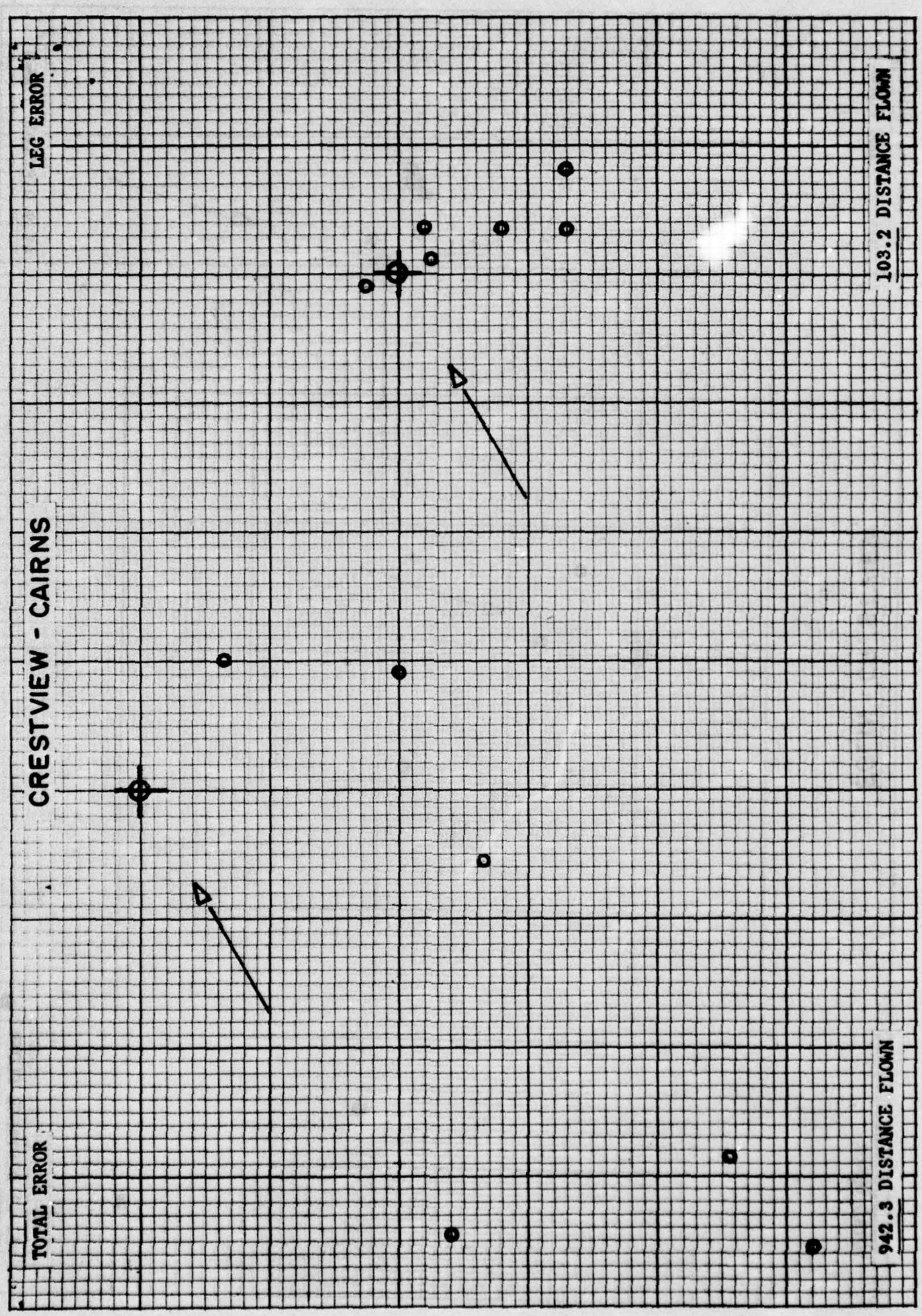

TALLAHASSEE - PERRY FOLEY
LEG ERROR
TOTAL ERROR
70.4 DISTANCE FLOWN
494.8 DISTANCE FLOWN


LEG ERROR
PERRY FOLEY - TYNDALL
180.1 DISTANCE FLOWN
TOTAL ERROR
624.9 DISTANCE FLOWN
12.9


TYNDALL - EGLIN
LEG ERROR
114.3 DISTANCE FLOWN
TOTAL ERROR
789.2 DISTANCE FLOWN


EGLIN - CRESTVIEW
LEG ERROR
49.9 DISTANCE FLOWN
TOTAL ERROR
839.1 DISTANCE FLOWN



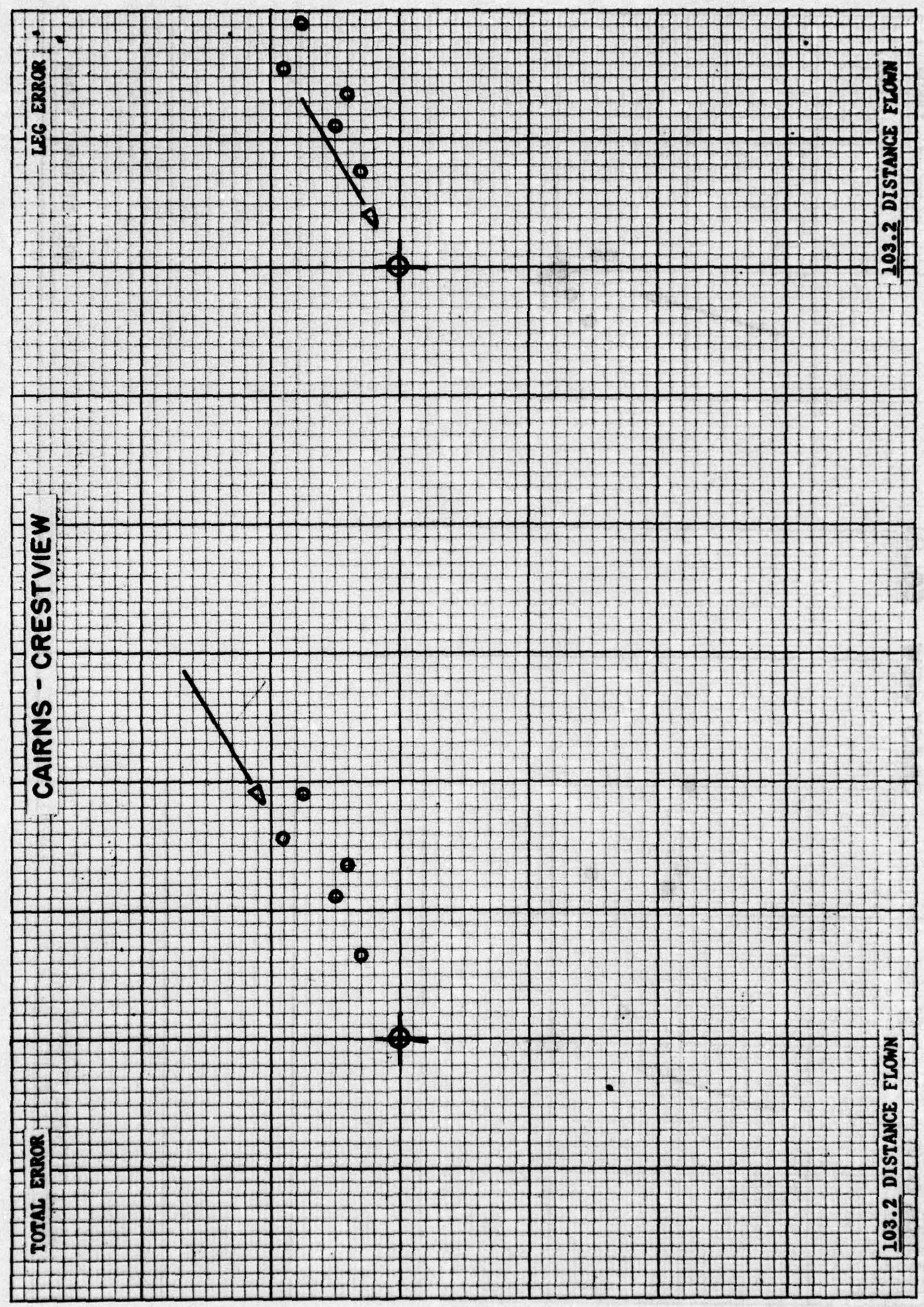
CRESTVIEW - CAIRNS
LEG ERROR
103.2 DISTANCE FLOWN
TOTAL ERROR
942.3 DISTANCE FLOWN

APPENDIX D

Doppler B Position Error

The data recorded in appendix H has been plotted on graphs to provide an immediately available readout of the Doppler navigation system leg error and total position error. These plots represent total system error. This data should not be used for direct comparison purposes without detailed analysis.

Graph Scale: One Inch = Two Kilometers



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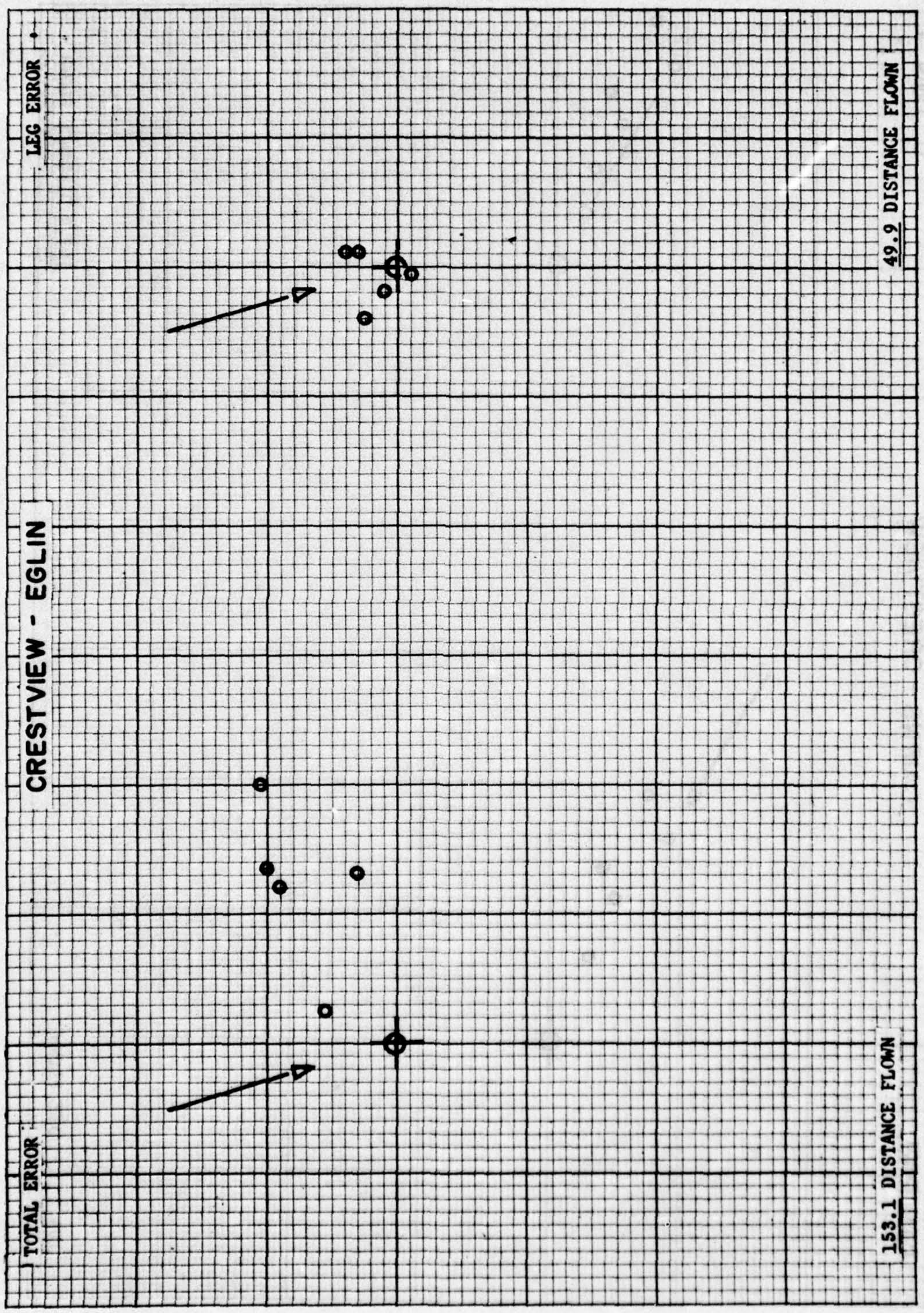
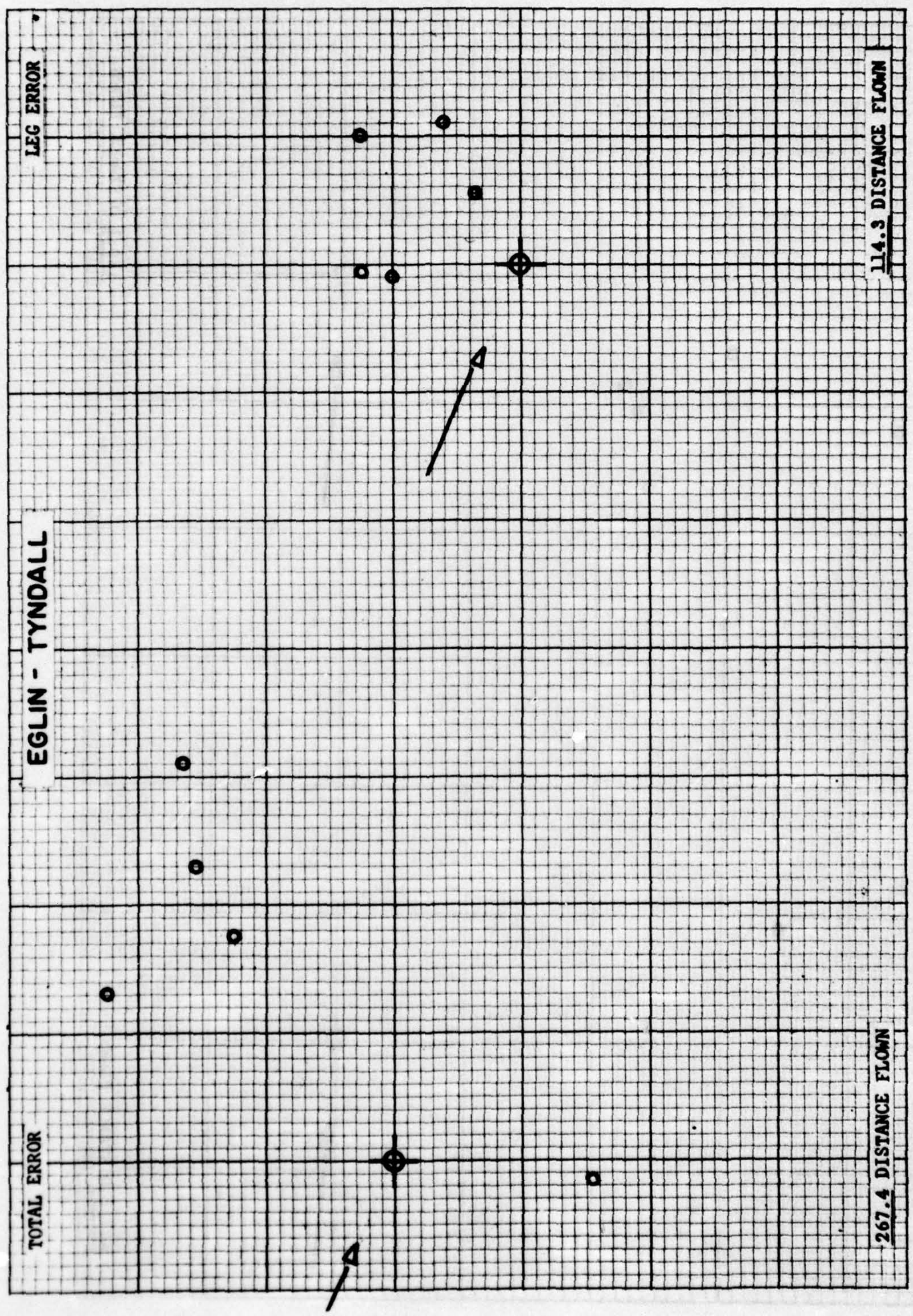
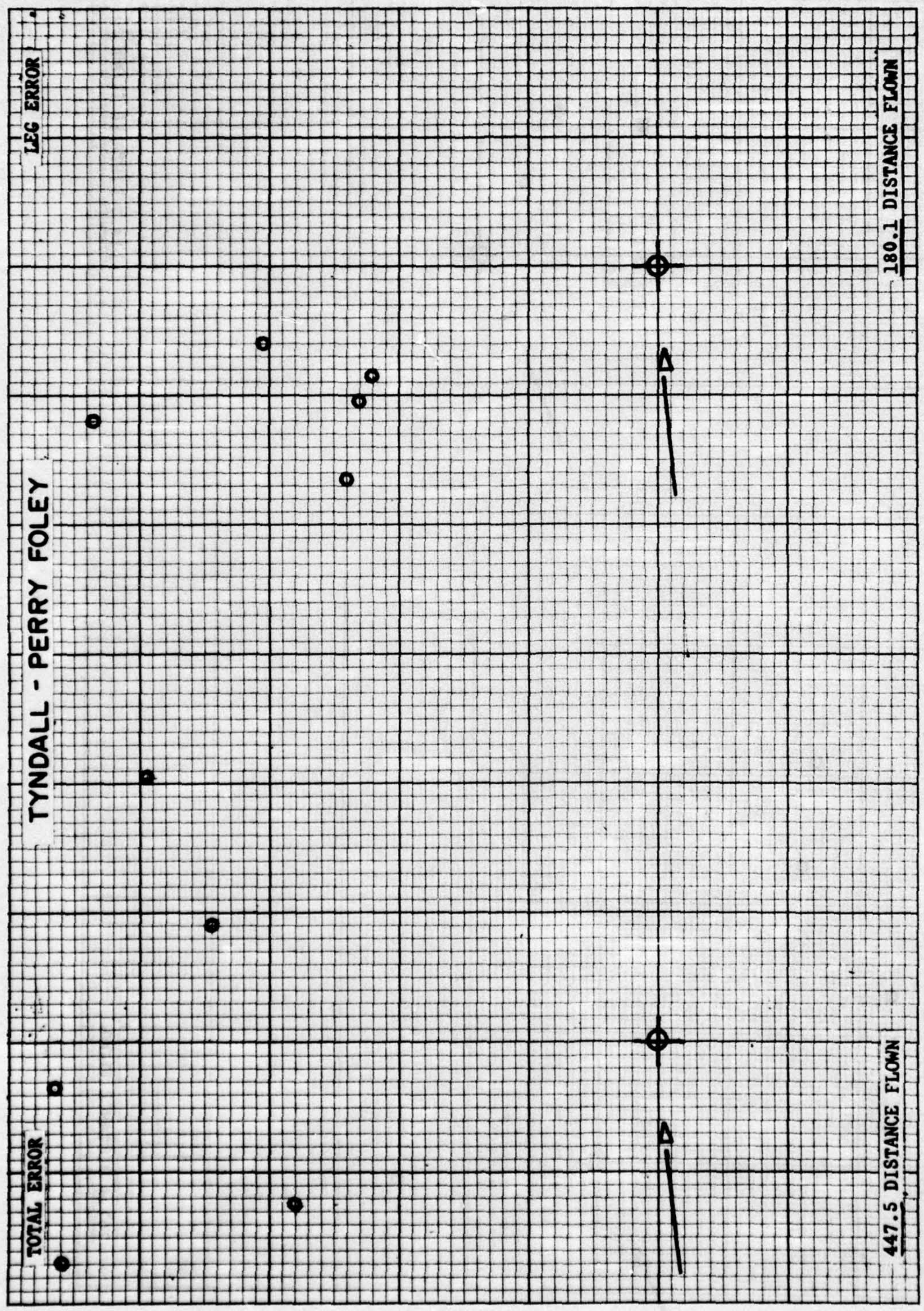
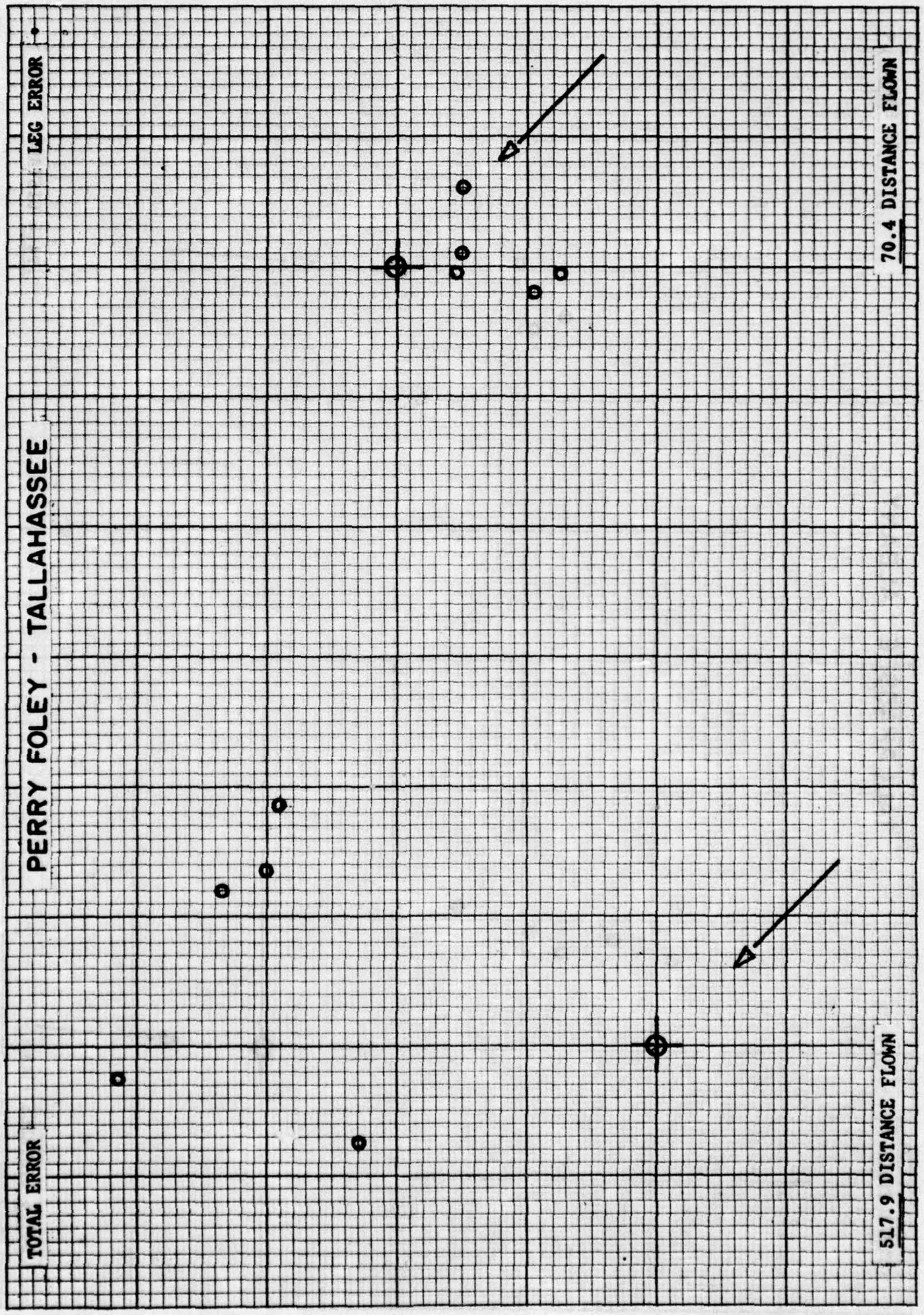
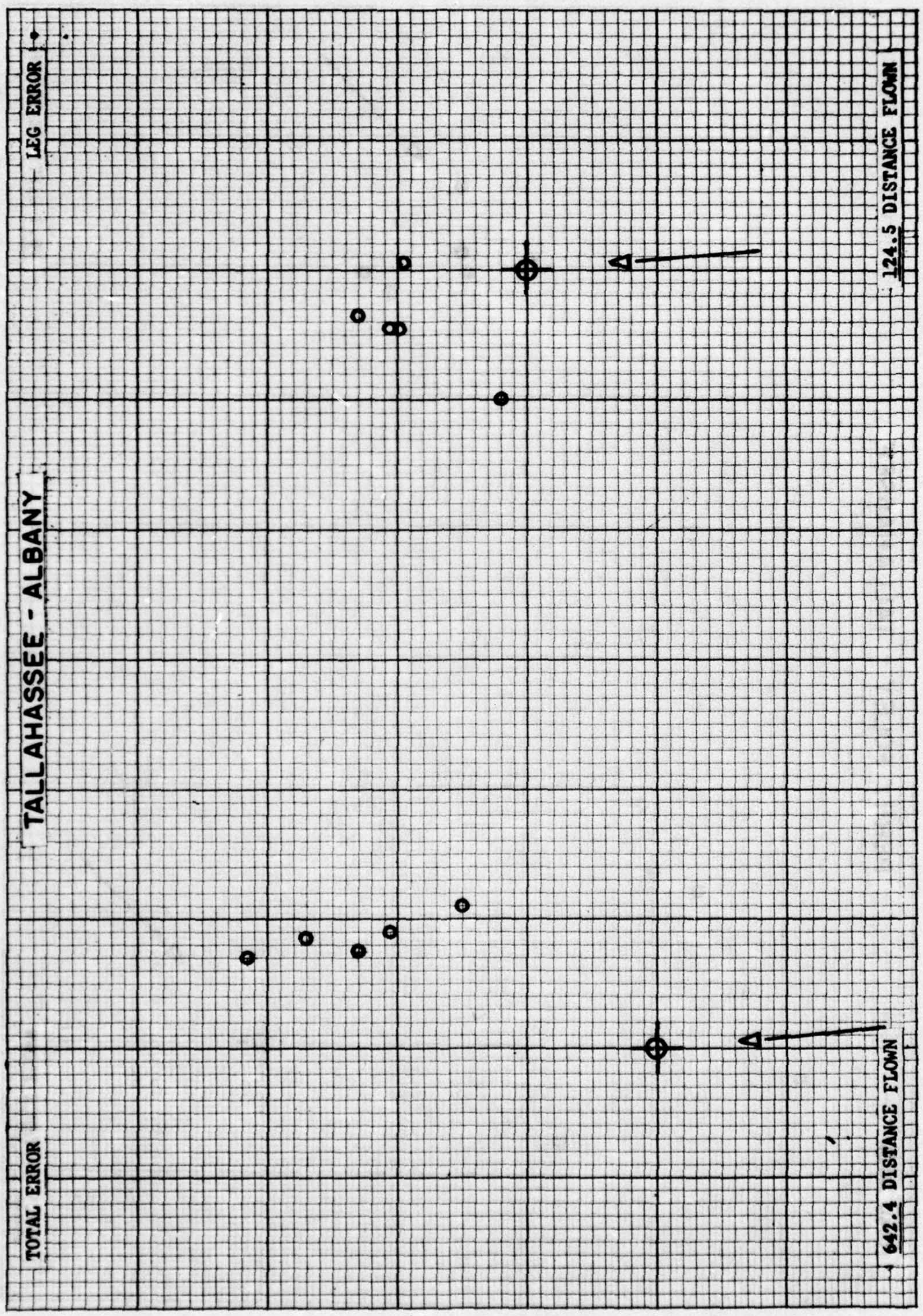

CRESTVIEW - EGLIN
LEG ERROR
TOTAL ERROR
49.9 DISTANCE FLOWN
153.1 DISTANCE FLOWN


EGLIN - TYNDALL
LEG ERROR
114.3 DISTANCE FLOWN
TOTAL ERROR
267.4 DISTANCE FLOWN

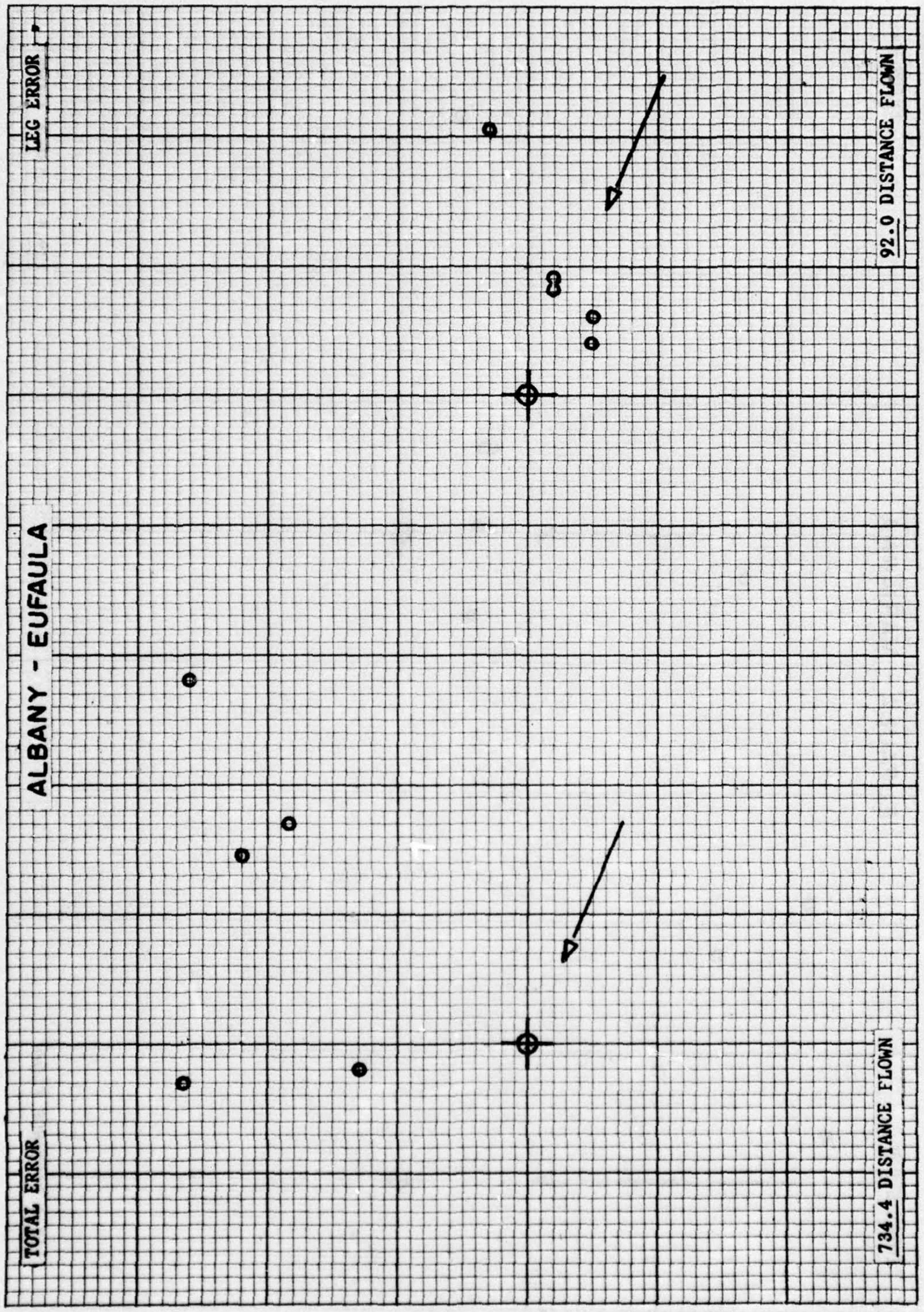


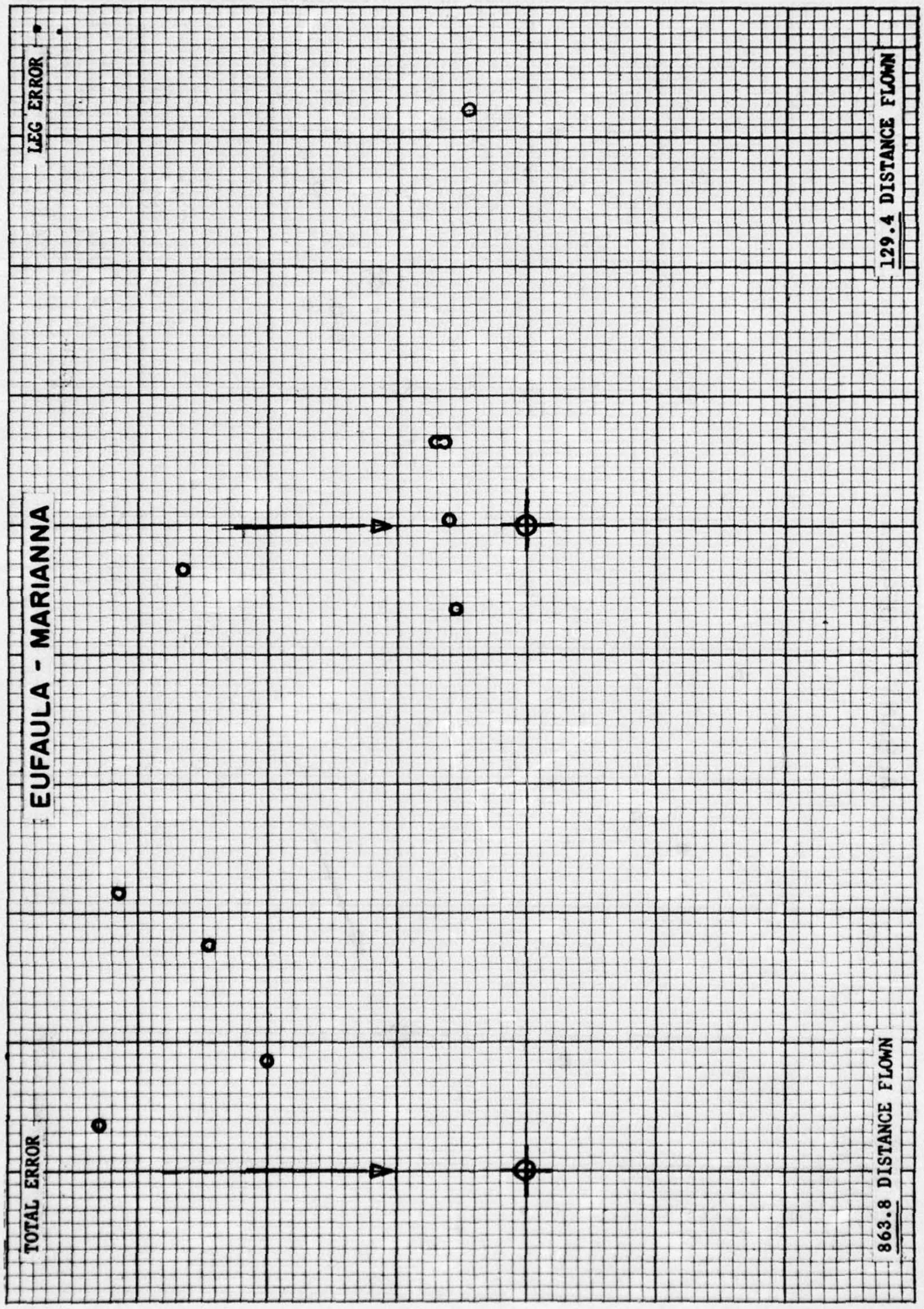
TYNDALL - PERRY FOLEY
LEG ERROR
180.1 DISTANCE FLOWN
TOTAL ERROR
447.5 DISTANCE FLOWN

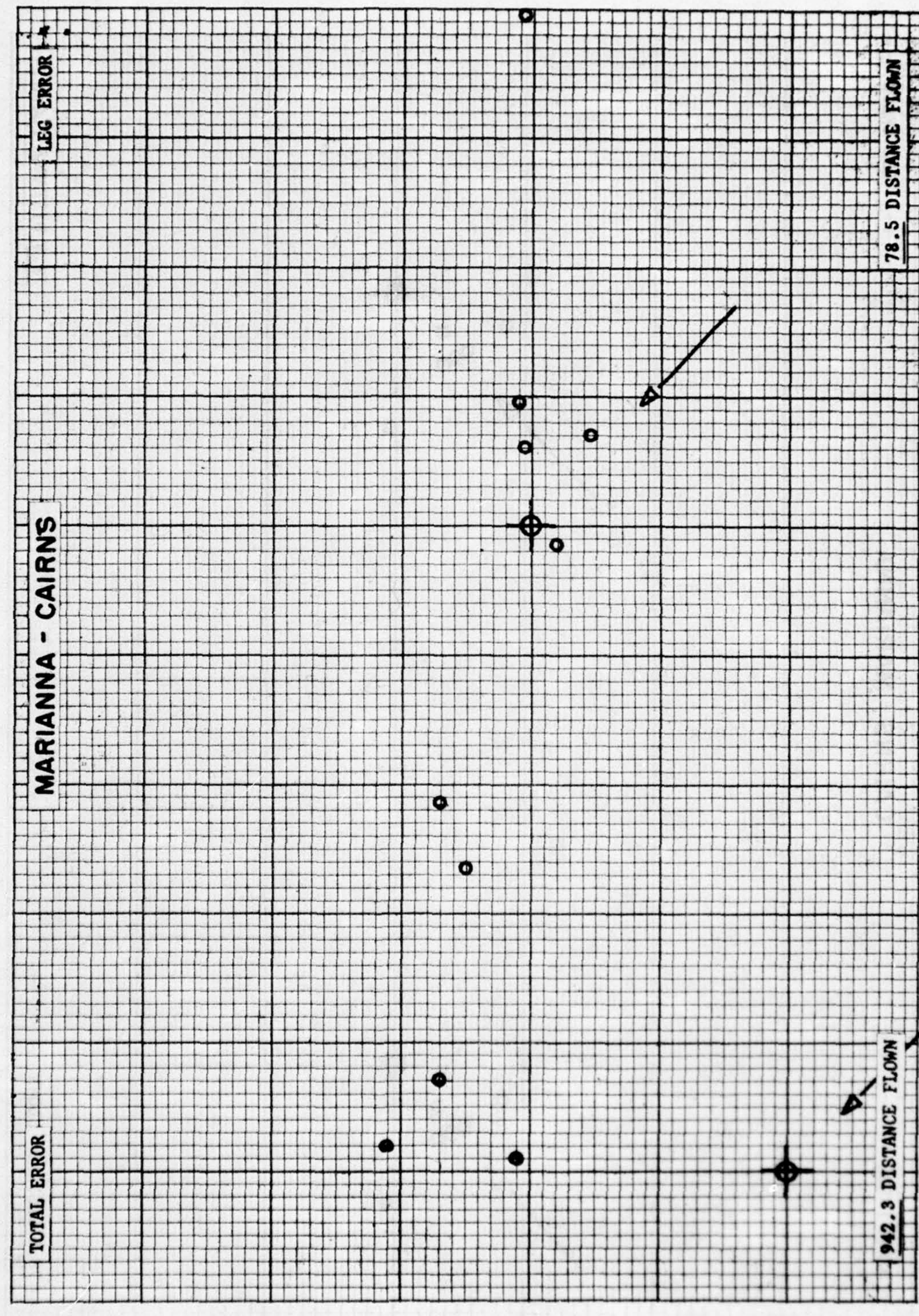

PERRY FOLEY - TALLAHASSEE
LEG ERROR
70.4 DISTANCE FLOWN
TOTAL ERROR
517.9 DISTANCE FLOWN

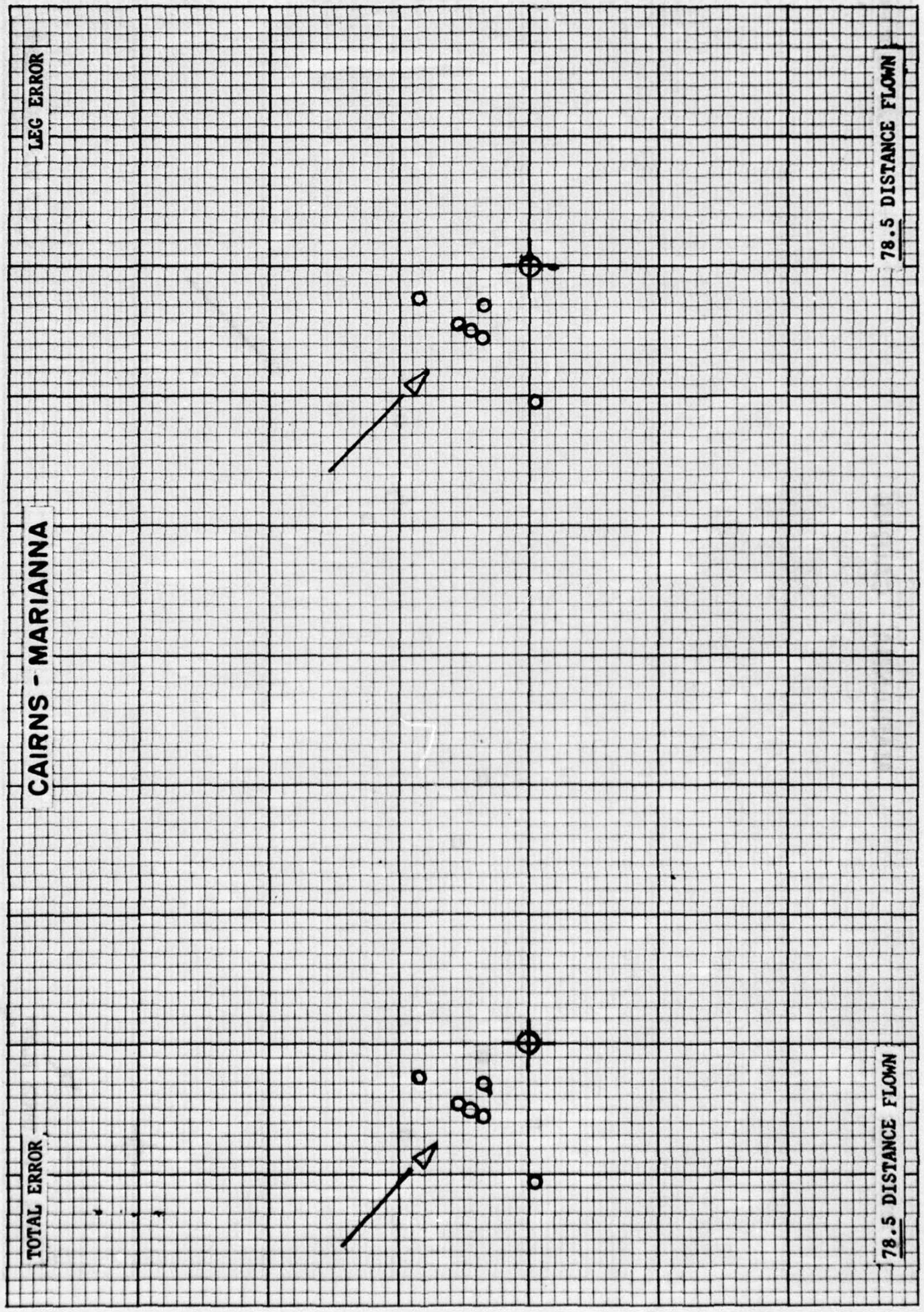


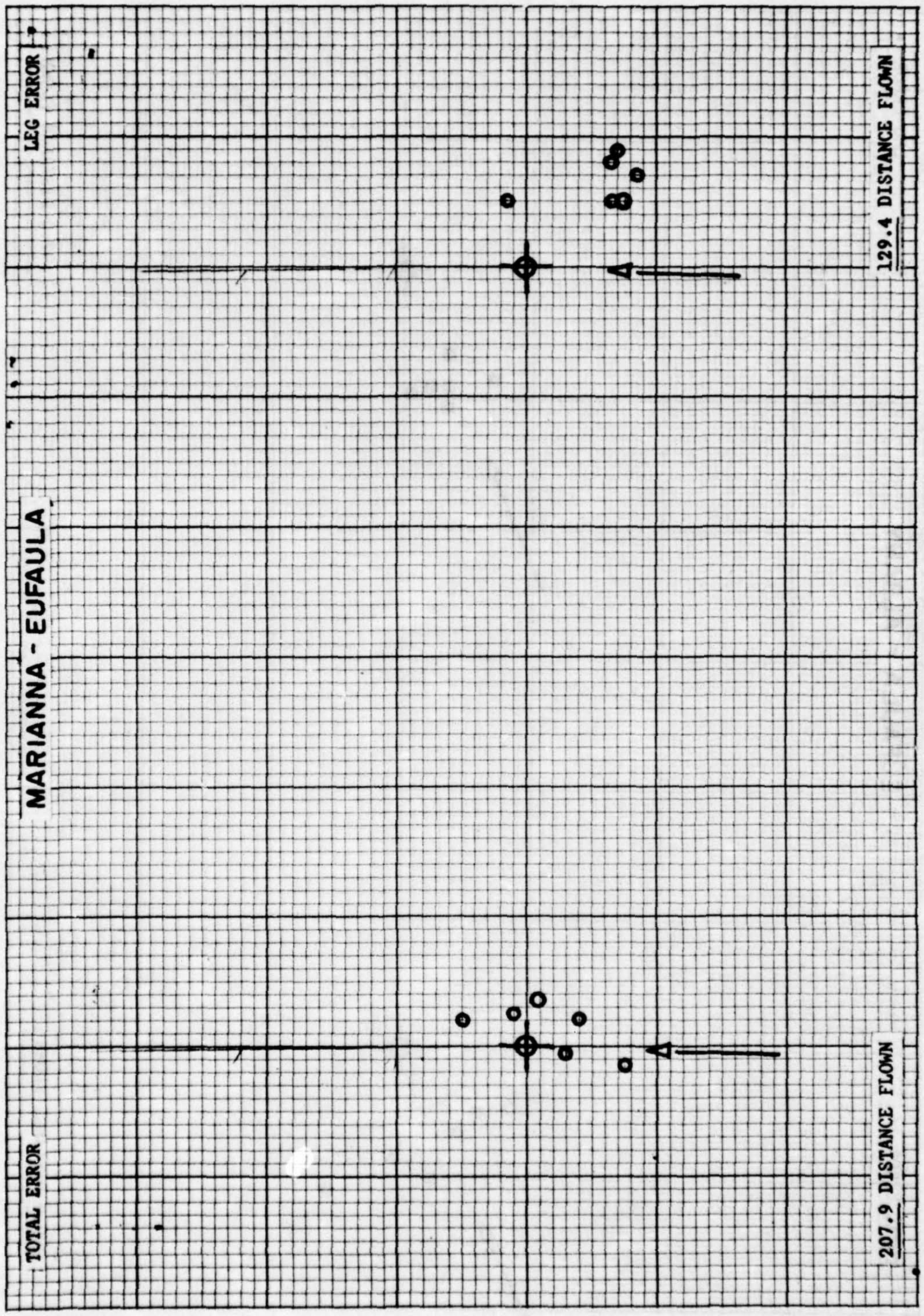
TALLAHASSEE - ALBANY
LEG ERROR
TOTAL ERROR
124.5 DISTANCE FLOWN
642.4 DISTANCE FLOWN

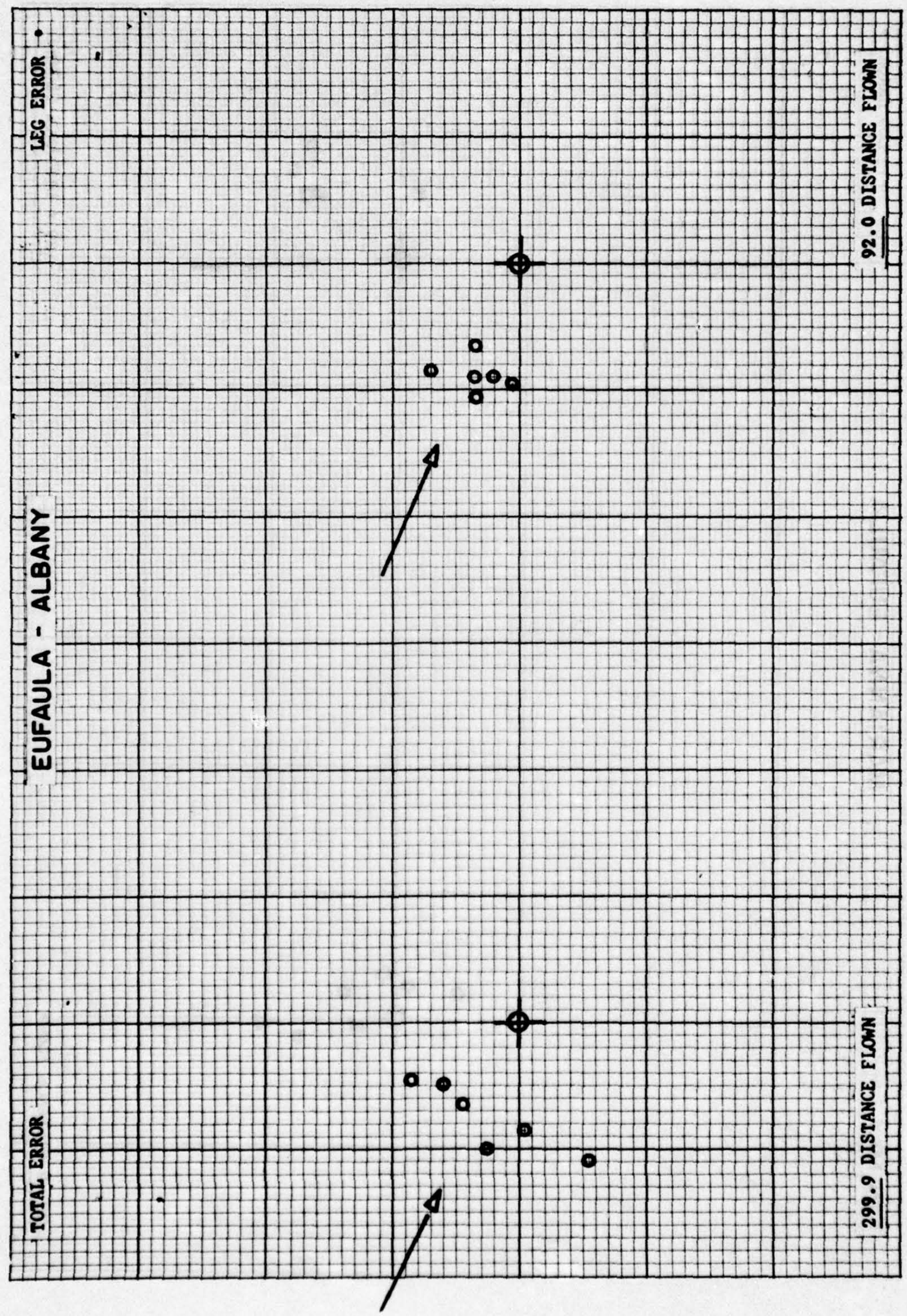

LEG ERROR
ALBANY - EUFAULA
TOTAL ERROR
92.0 DISTANCE FLOWN
734.4 DISTANCE FLOWN

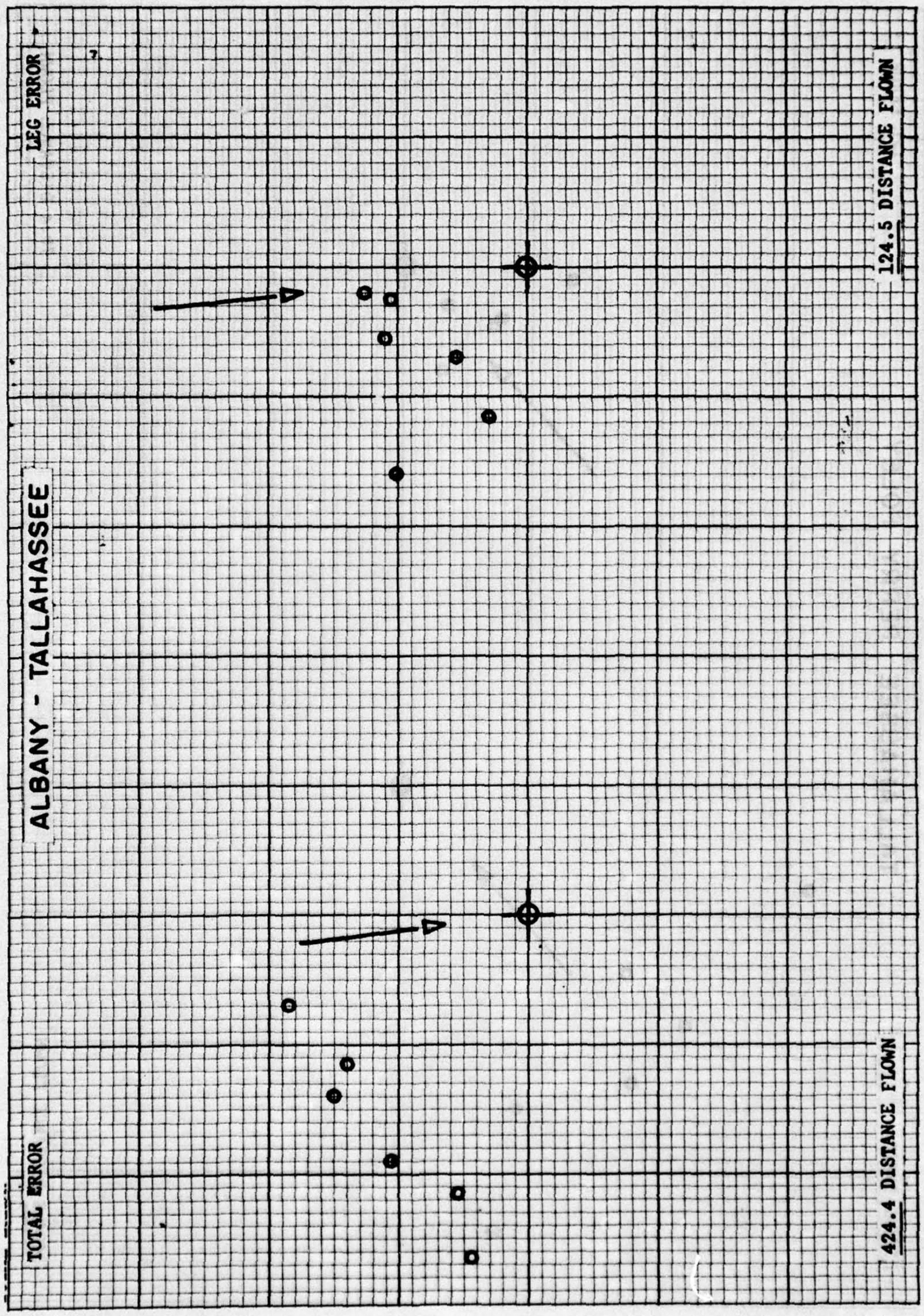

EUFAULA - MARIANNA
LEG ERROR
129.4 DISTANCE FLOWN
TOTAL ERROR
863.8 DISTANCE FLOWN

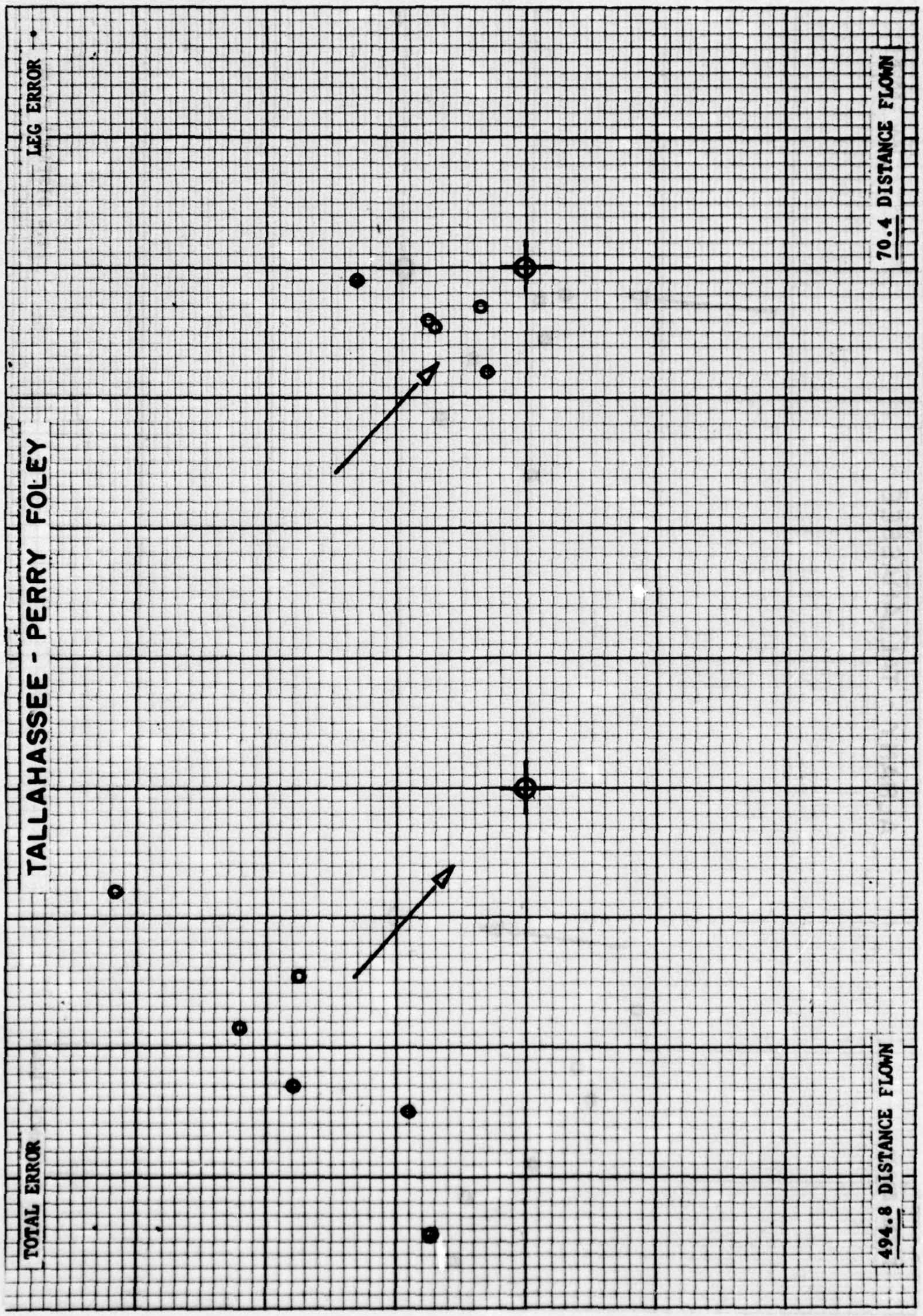

MARIANNA - CAIRNS
LEG ERROR
78.5 DISTANCE FLOWN
TOTAL ERROR
942.3 DISTANCE FLOWN

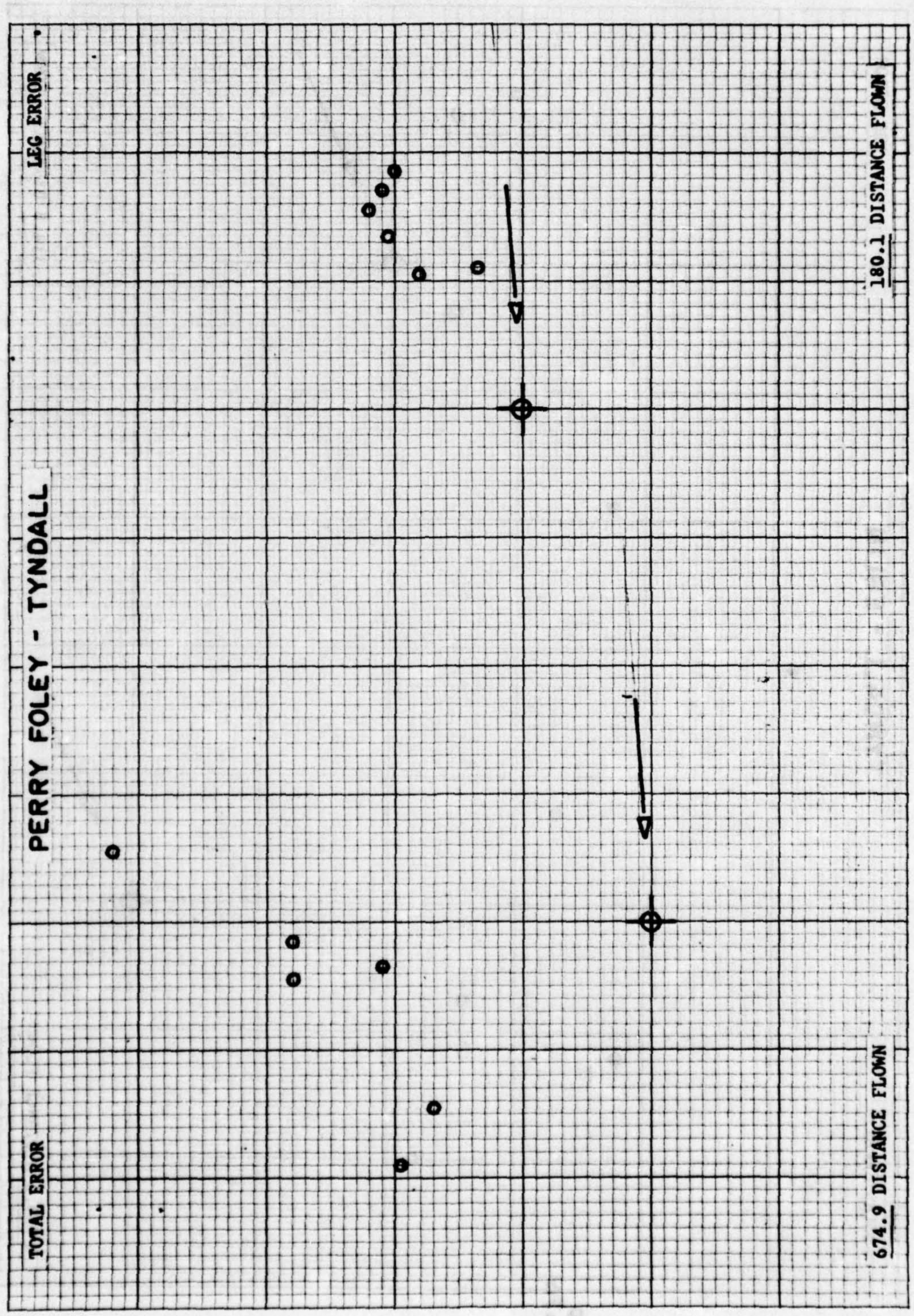

CAIRNS - MARIANNA
LEG ERROR
78.5 DISTANCE FLOWN
TOTAL ERROR
78.5 DISTANCE FLOWN

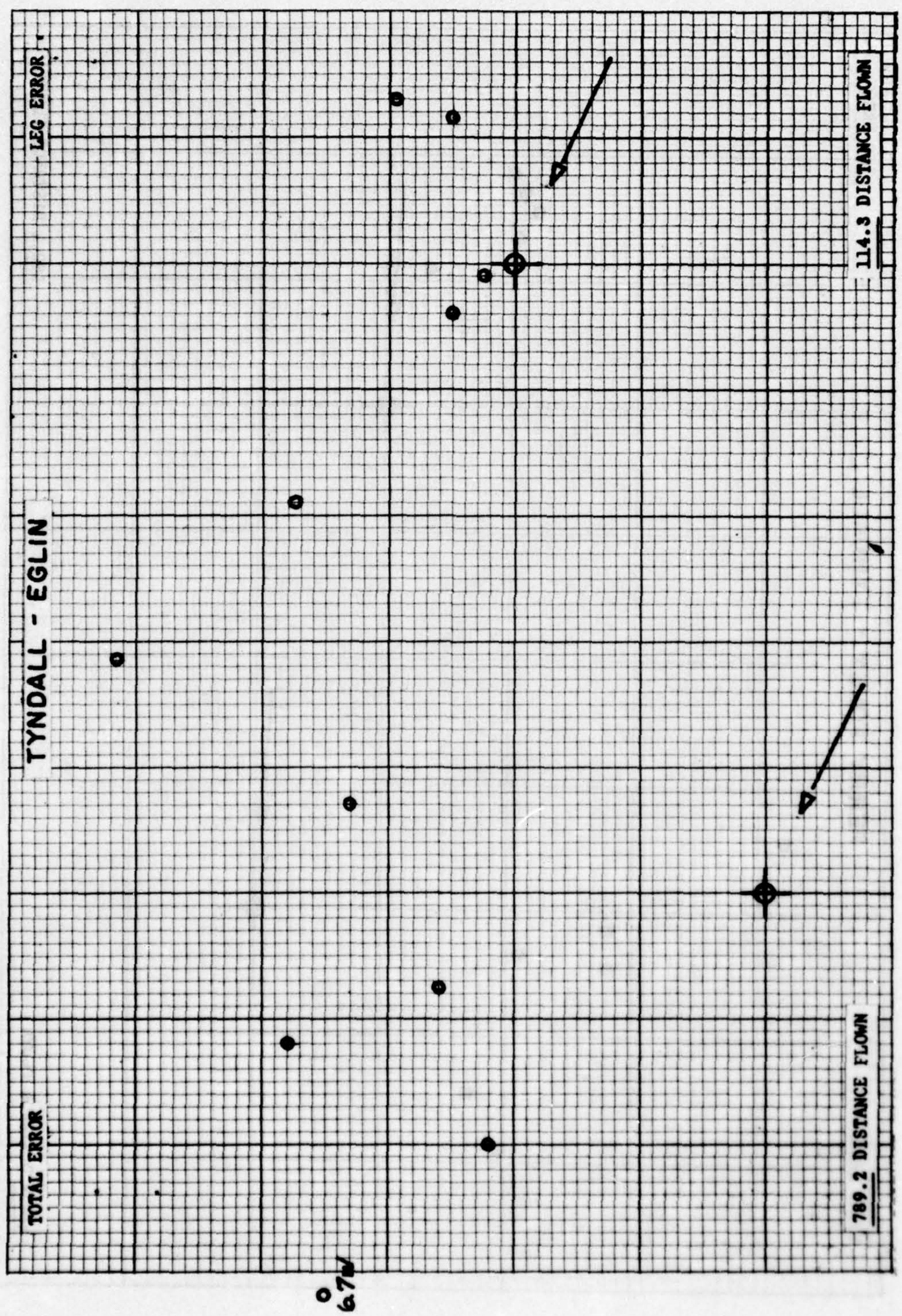

MARIANNA - EUFAULA
LEG ERROR
129.4 DISTANCE FLOWN
TOTAL ERROR
207.9 DISTANCE FLOWN

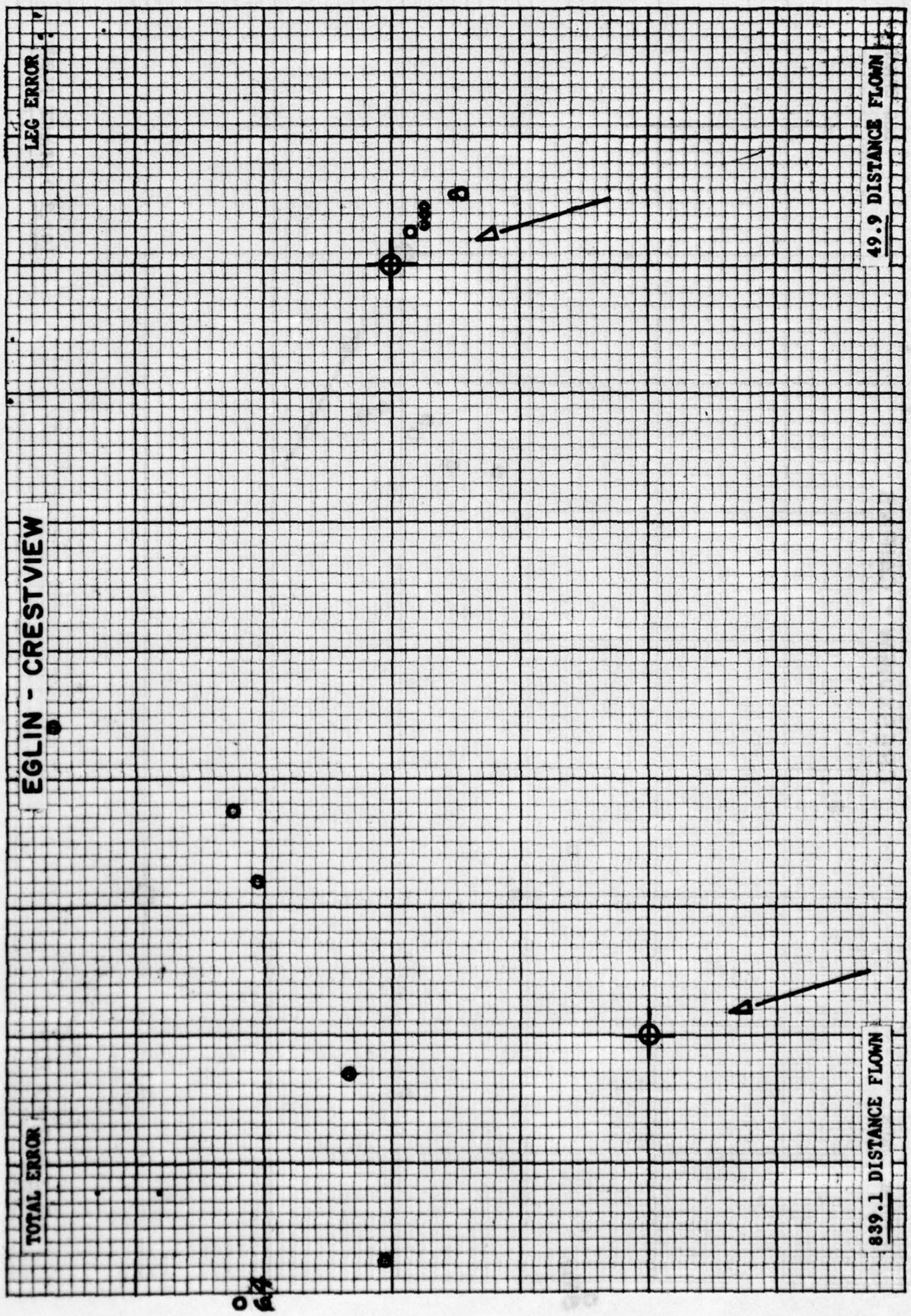

EUFAULA - ALBANY
LEG ERROR
92.0 DISTANCE FLOWN
TOTAL ERROR
299.9 DISTANCE FLOWN

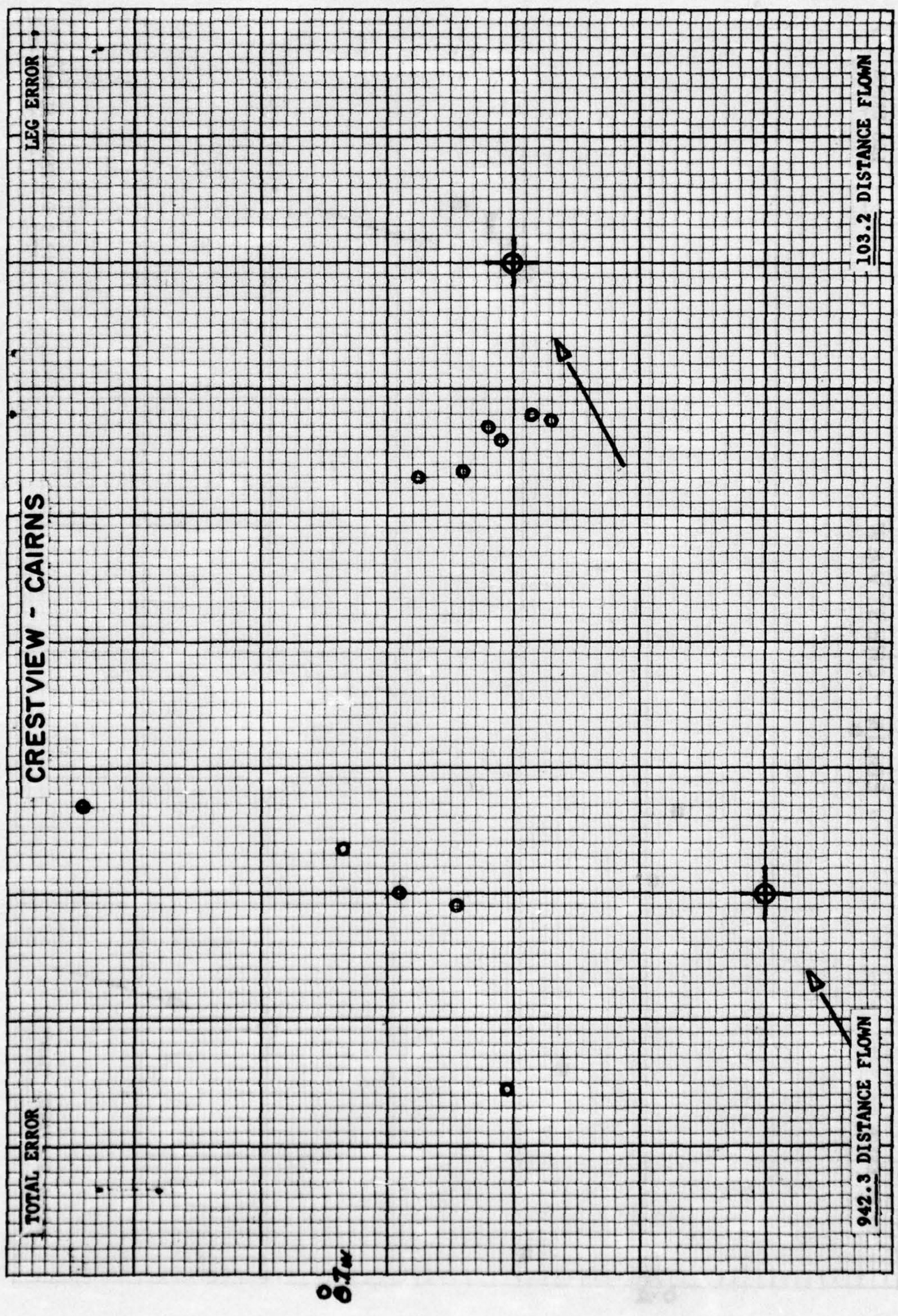

ALBANY - TALLAHASSEE
LEG ERROR
124.5 DISTANCE FLOWN
TOTAL ERROR
424.4 DISTANCE FLOWN


TALLAHASSEE - PERRY FOLEY
LEG ERROR
70.4 DISTANCE FLOWN
TOTAL ERROR
494.8 DISTANCE FLOWN


PERRY FOLEY - TYNDALL
LEG ERROR
180.1 DISTANCE FLOWN
TOTAL ERROR
674.9 DISTANCE FLOWN


TYNDALL - EGLIN
LEG ERROR
114.3 DISTANCE FLOWN
TOTAL ERROR
789.2 DISTANCE FLOWN
6.7W


EGLIN - CRESTVIEW
LEG ERROR
49.9 DISTANCE FLOWN
TOTAL ERROR
839.1 DISTANCE FLOWN

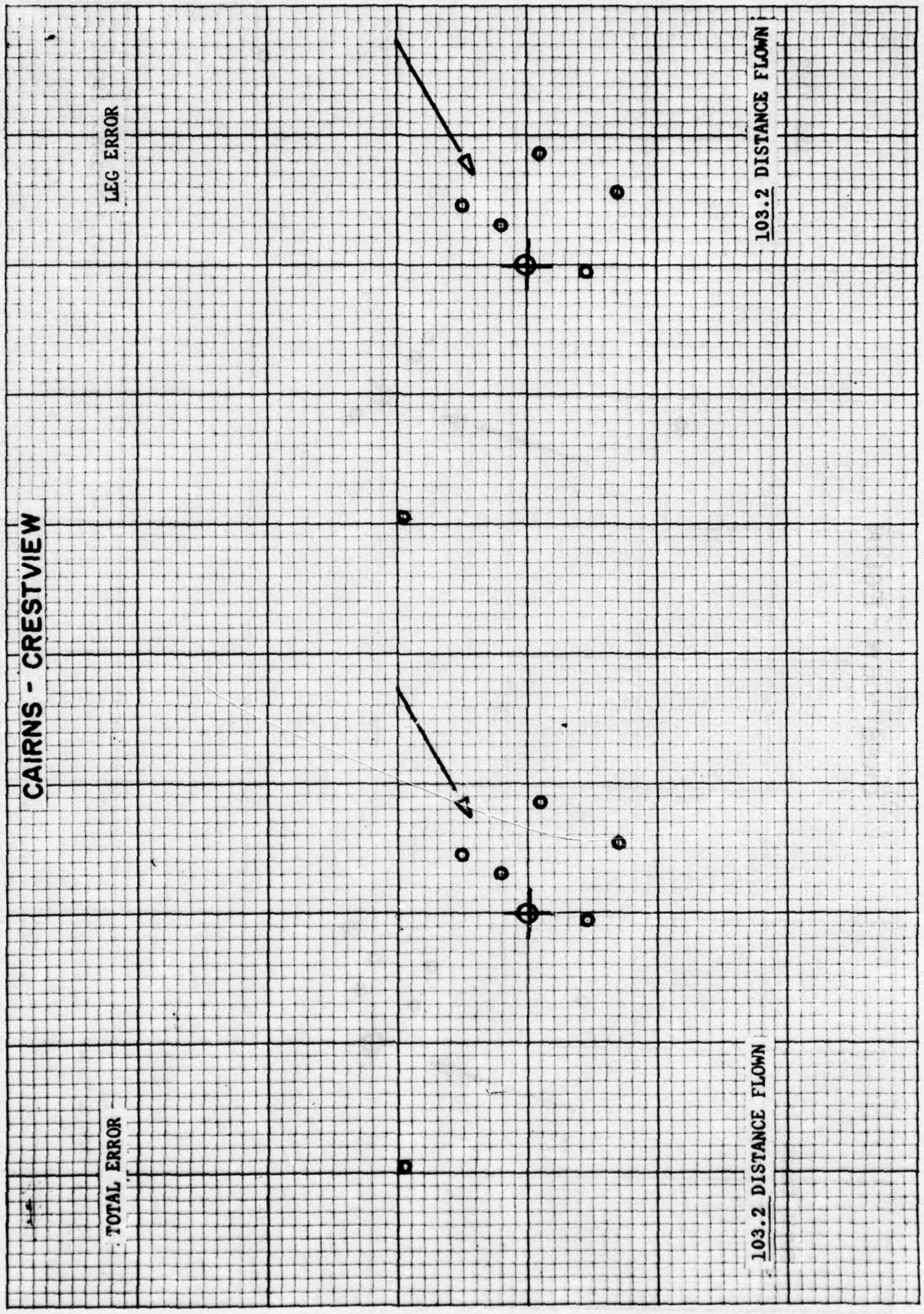

CRESTVIEW - CAIRNS
LEG ERROR
TOTAL ERROR
103.2 DISTANCE FLOWN
942.3 DISTANCE FLOWN
0
0.7

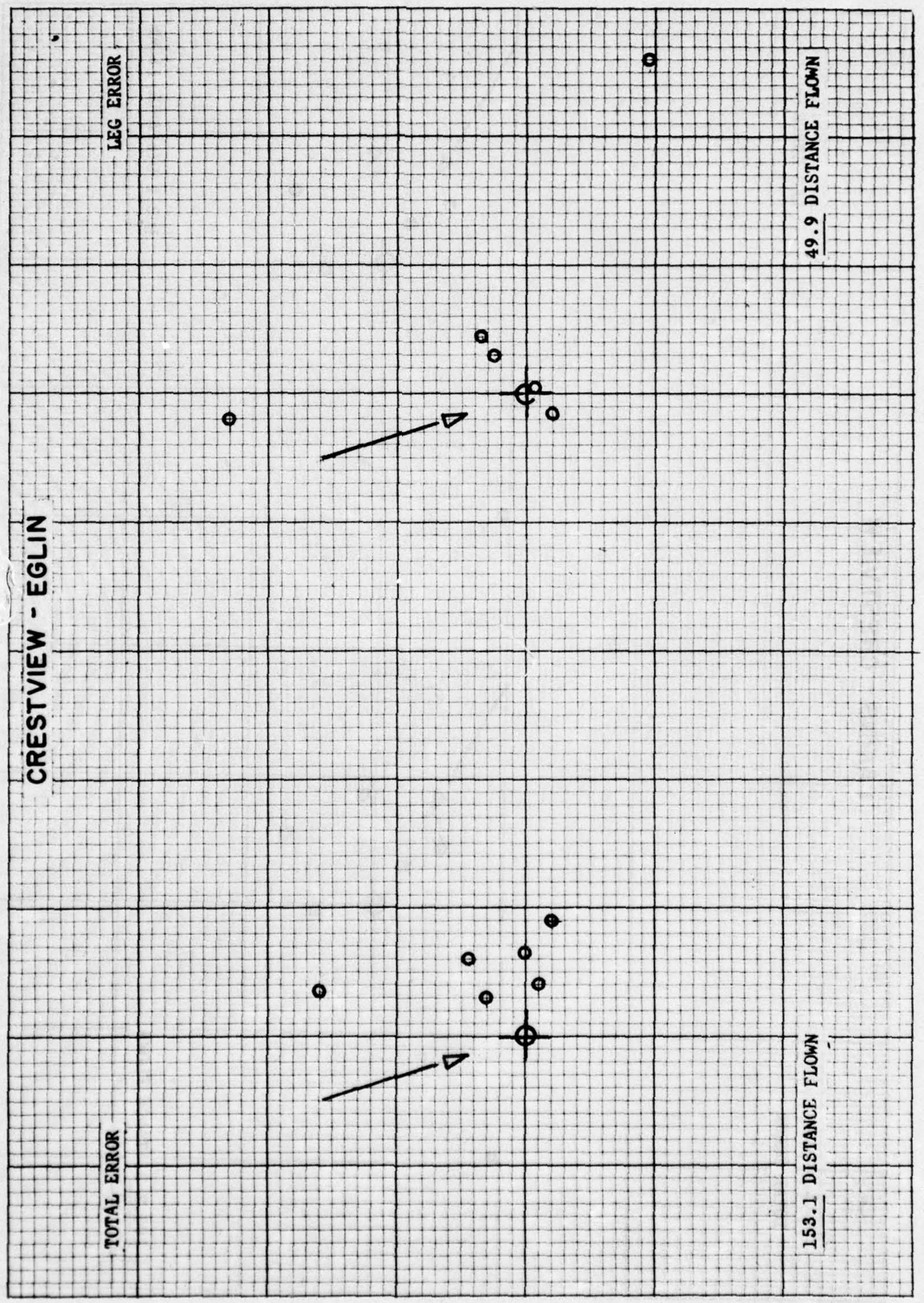
APPENDIX E

Doppler C(FW) Position Error

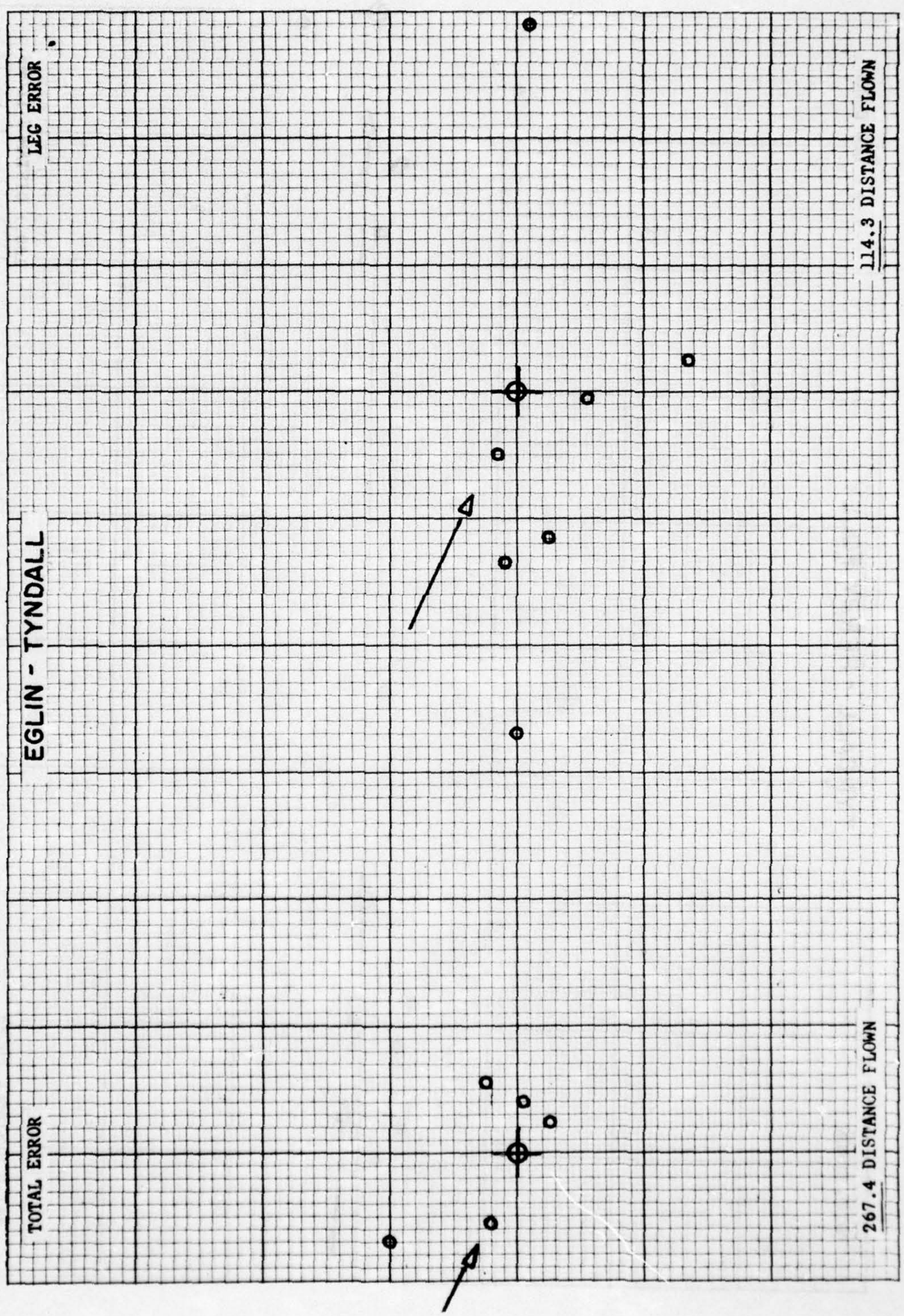
The data recorded in appendix I has been plotted on graphs to provide an immediately available readout of the Doppler navigation system leg error and total position error. These plots represent total system error. This data should not be used for direct comparison purposes without detailed analysis.

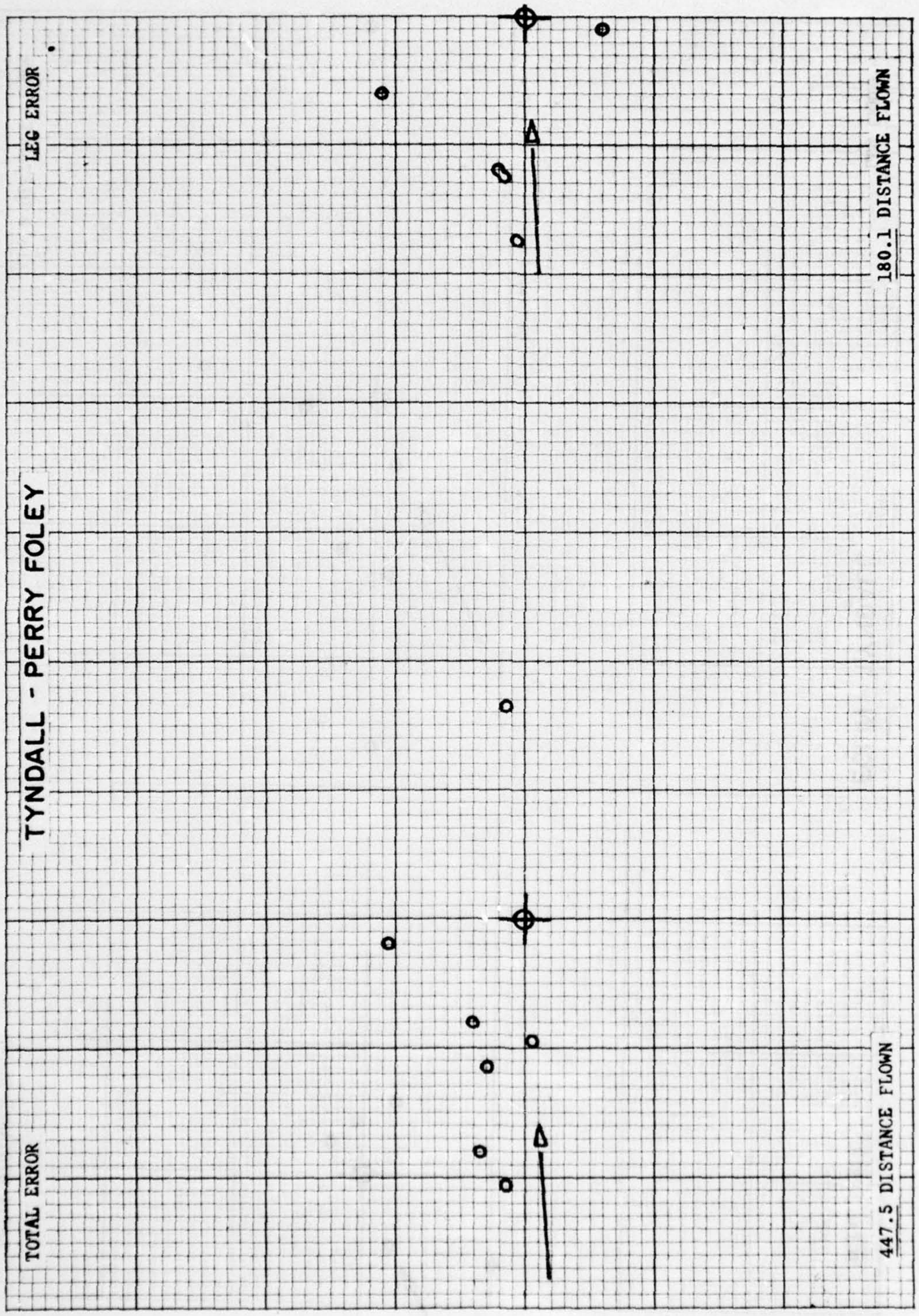
Graph Scale: One Inch = Two Kilometers

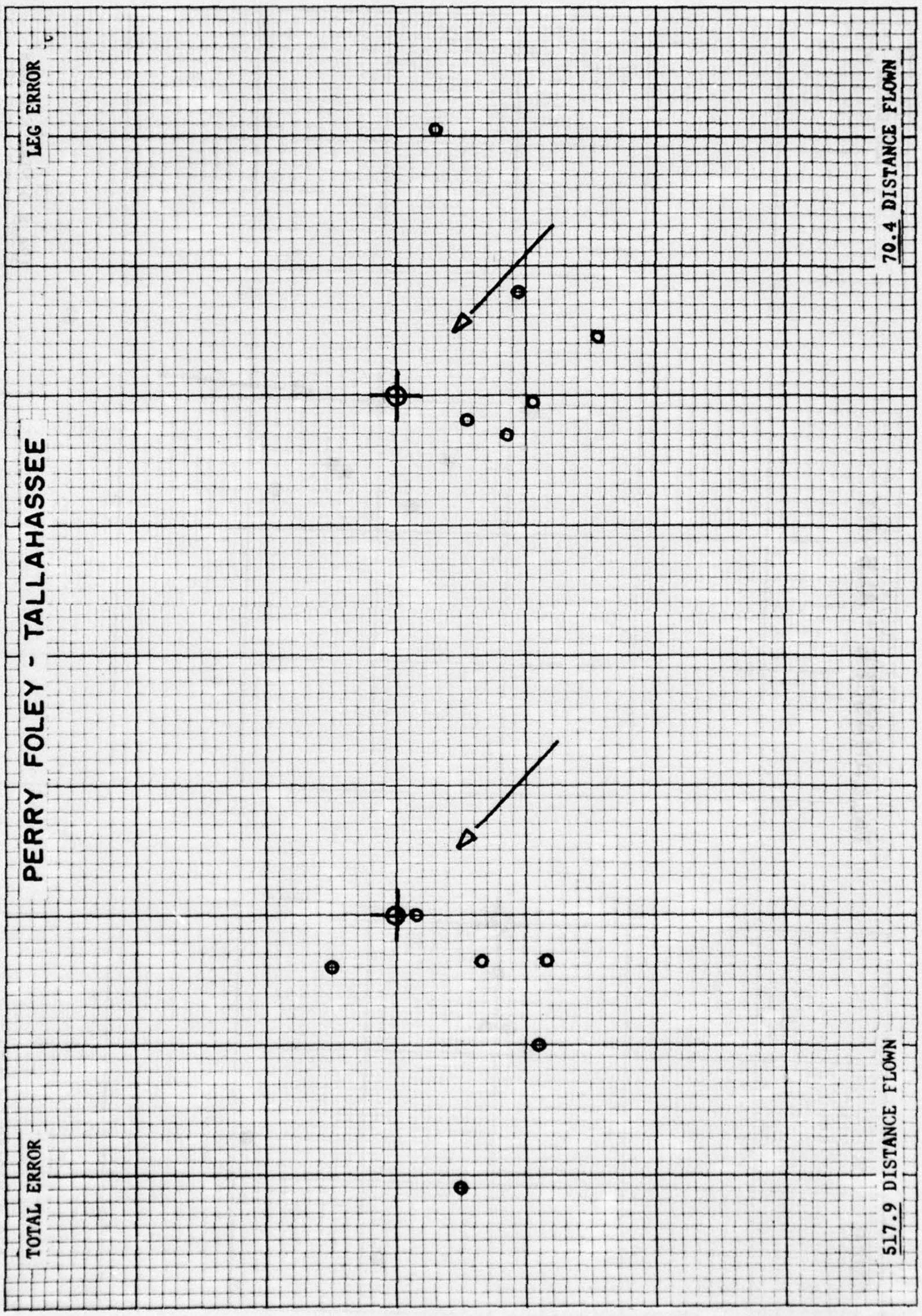

CAIRNS - CRESTVIEW
LEG ERROR
103.2 DISTANCE FLOWN
TOTAL ERROR
103.2 DISTANCE FLOWN

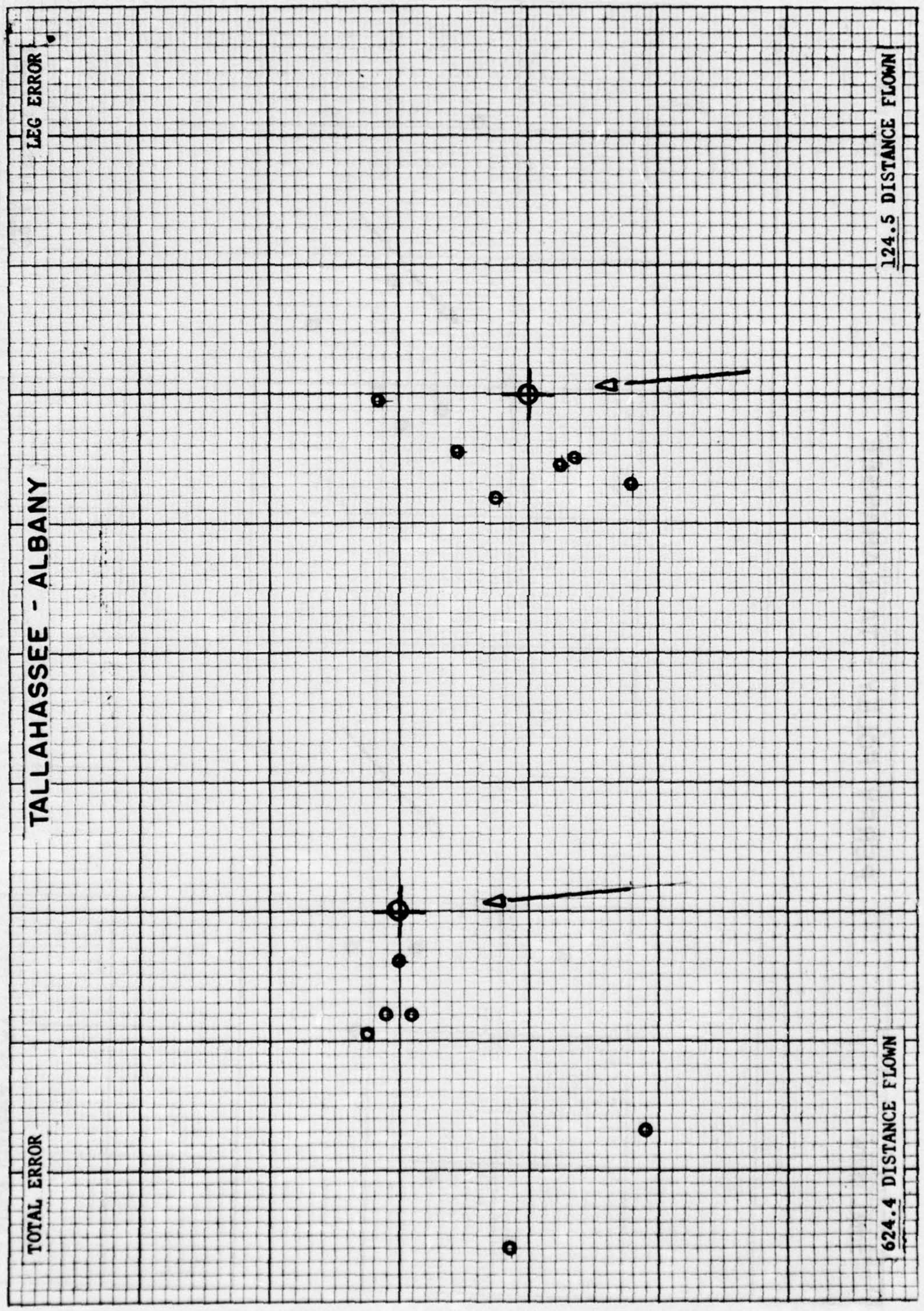


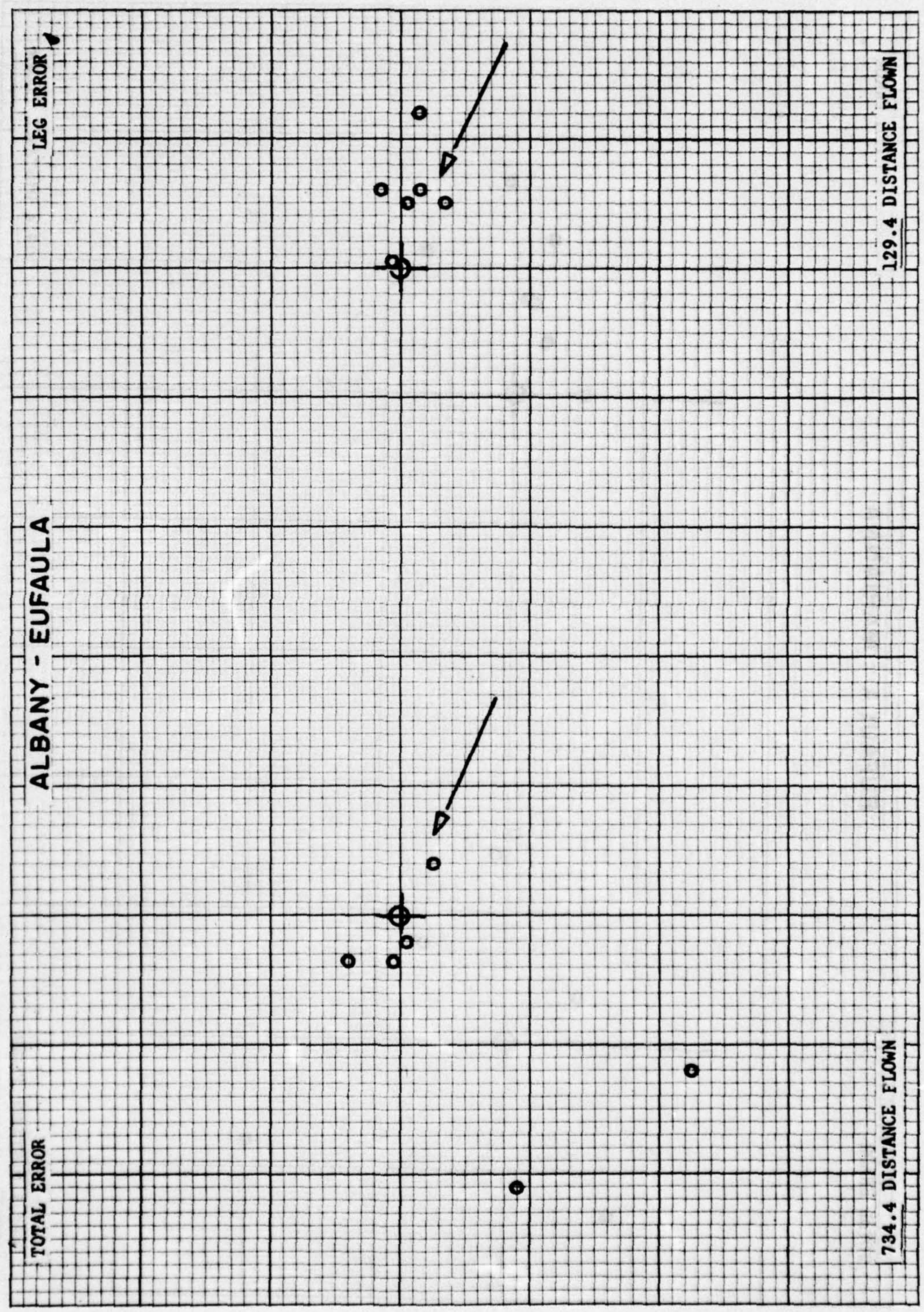
CRESTVIEW - EGLIN
LEG ERROR
49.9 DISTANCE FLOWN
TOTAL ERROR
153.1 DISTANCE FLOWN

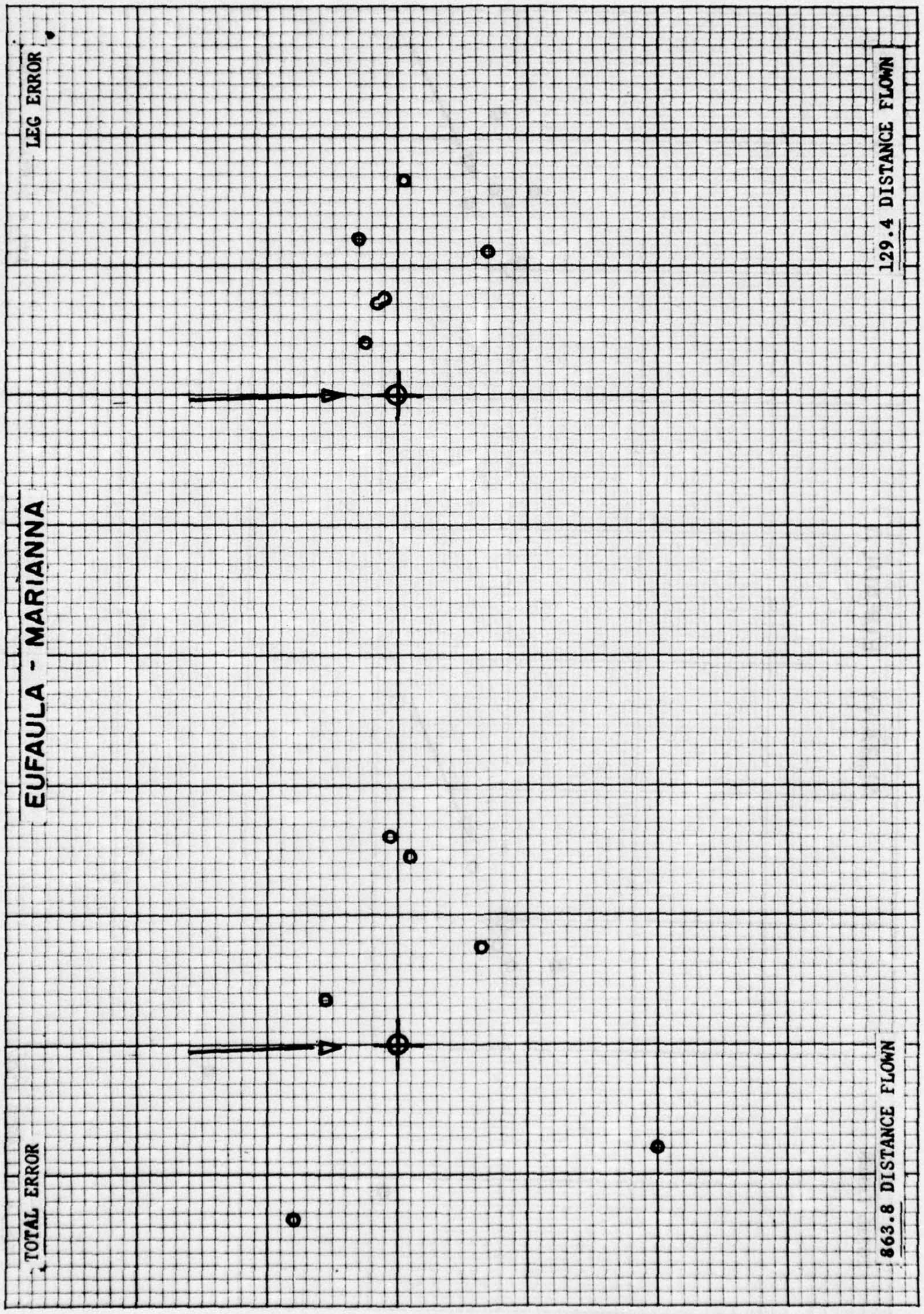

EGLIN - TYNDALL
LEG ERROR
114.3 DISTANCE FLOWN
TOTAL ERROR
267.4 DISTANCE FLOWN

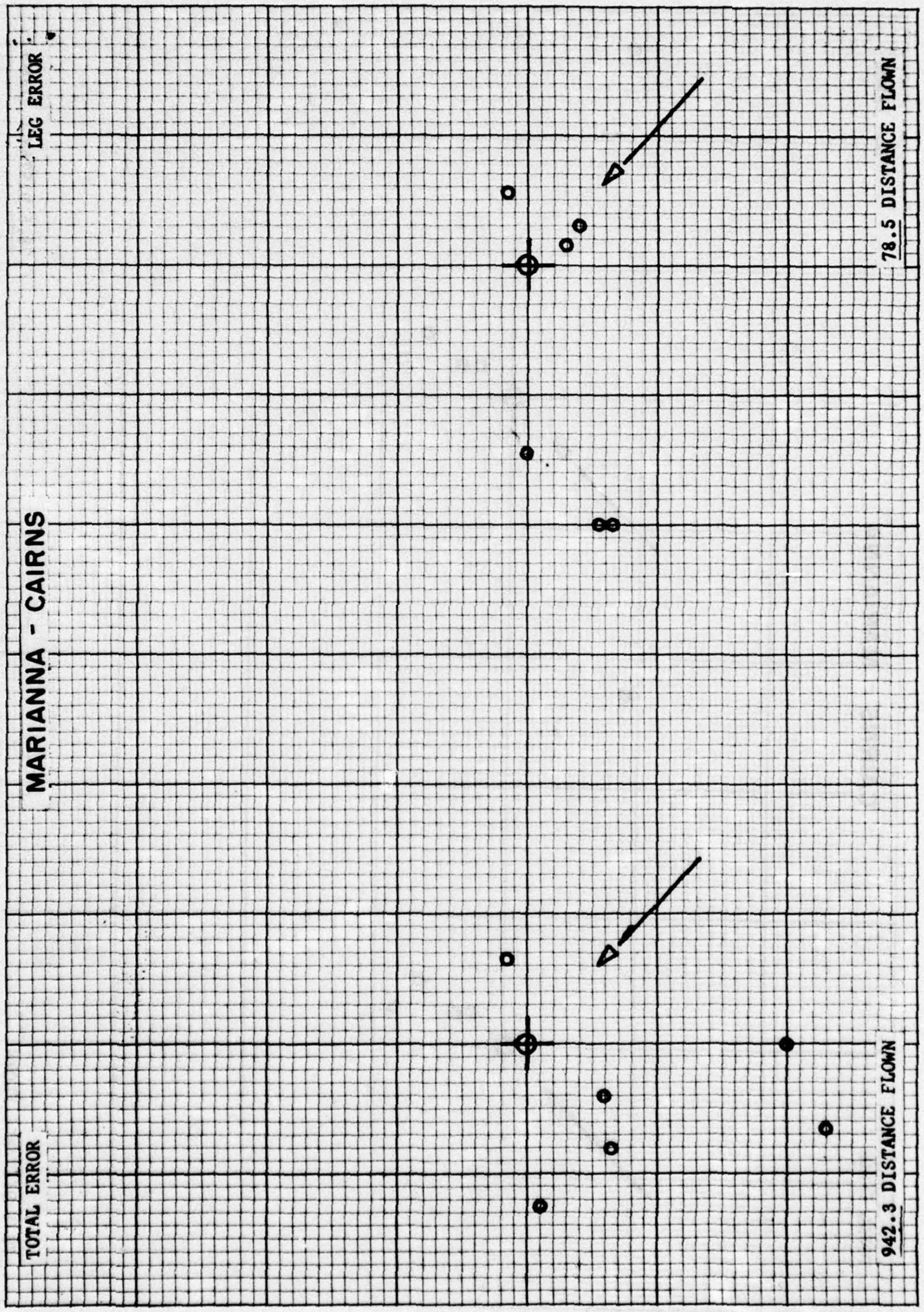

TYNDALL - PERRY FOLEY
LEG ERROR
180.1 DISTANCE FLOWN
TOTAL ERROR
447.5 DISTANCE FLOWN


PERRY FOLEY - TALLAHASSEE
LEG ERROR
70.4 DISTANCE FLOWN
TOTAL ERROR
517.9 DISTANCE FLOWN


TALLAHASSEE - ALBANY
LEG ERROR
124.5 DISTANCE FLOWN
TOTAL ERROR
624.4 DISTANCE FLOWN


ALBANY - EUFAULA
LEG ERROR
129.4 DISTANCE FLOWN
TOTAL ERROR
734.4 DISTANCE FLOWN


EUFAULA - MARIANNA
LEG ERROR
129.4 DISTANCE FLOWN
TOTAL ERROR
863.8 DISTANCE FLOWN



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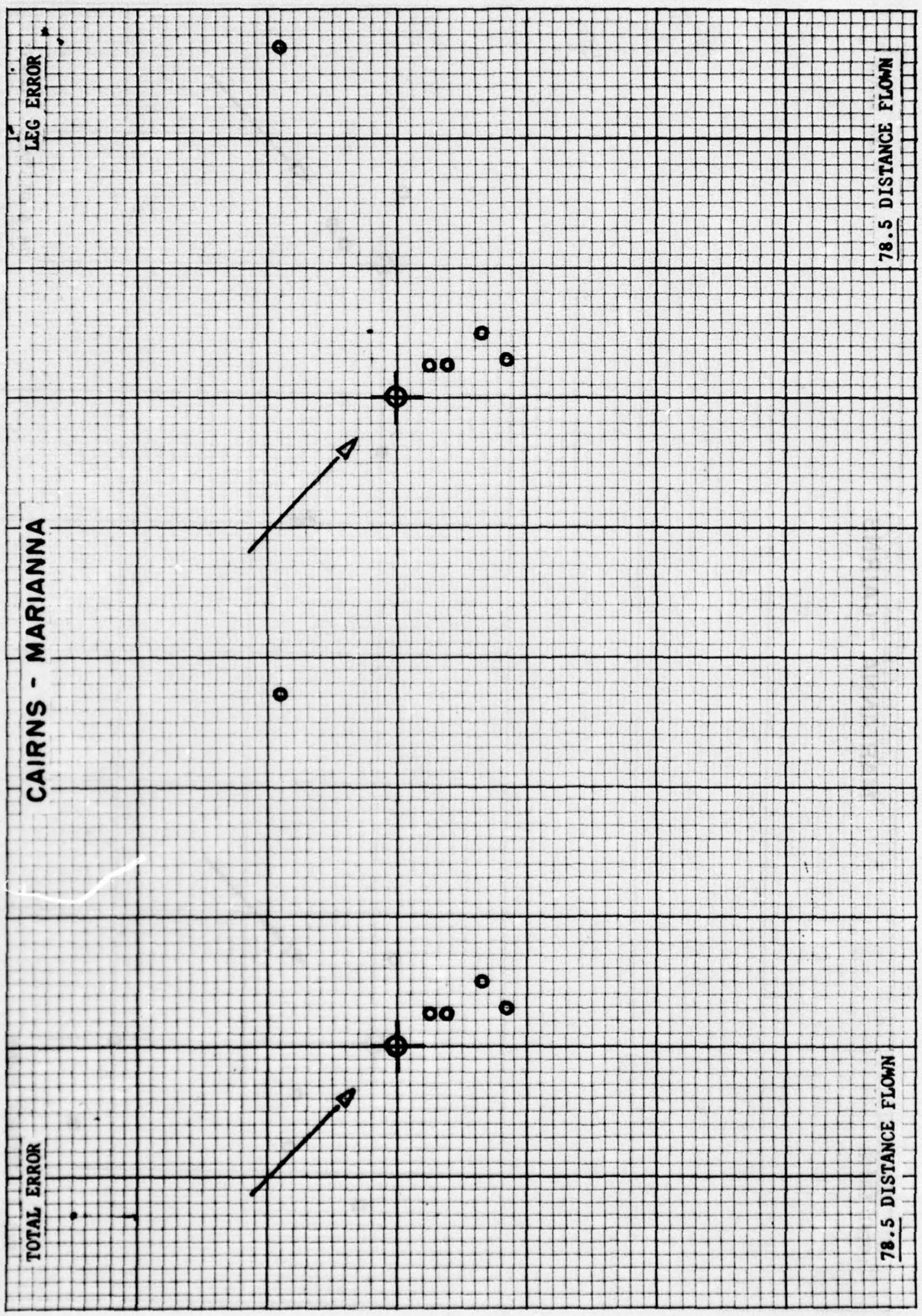
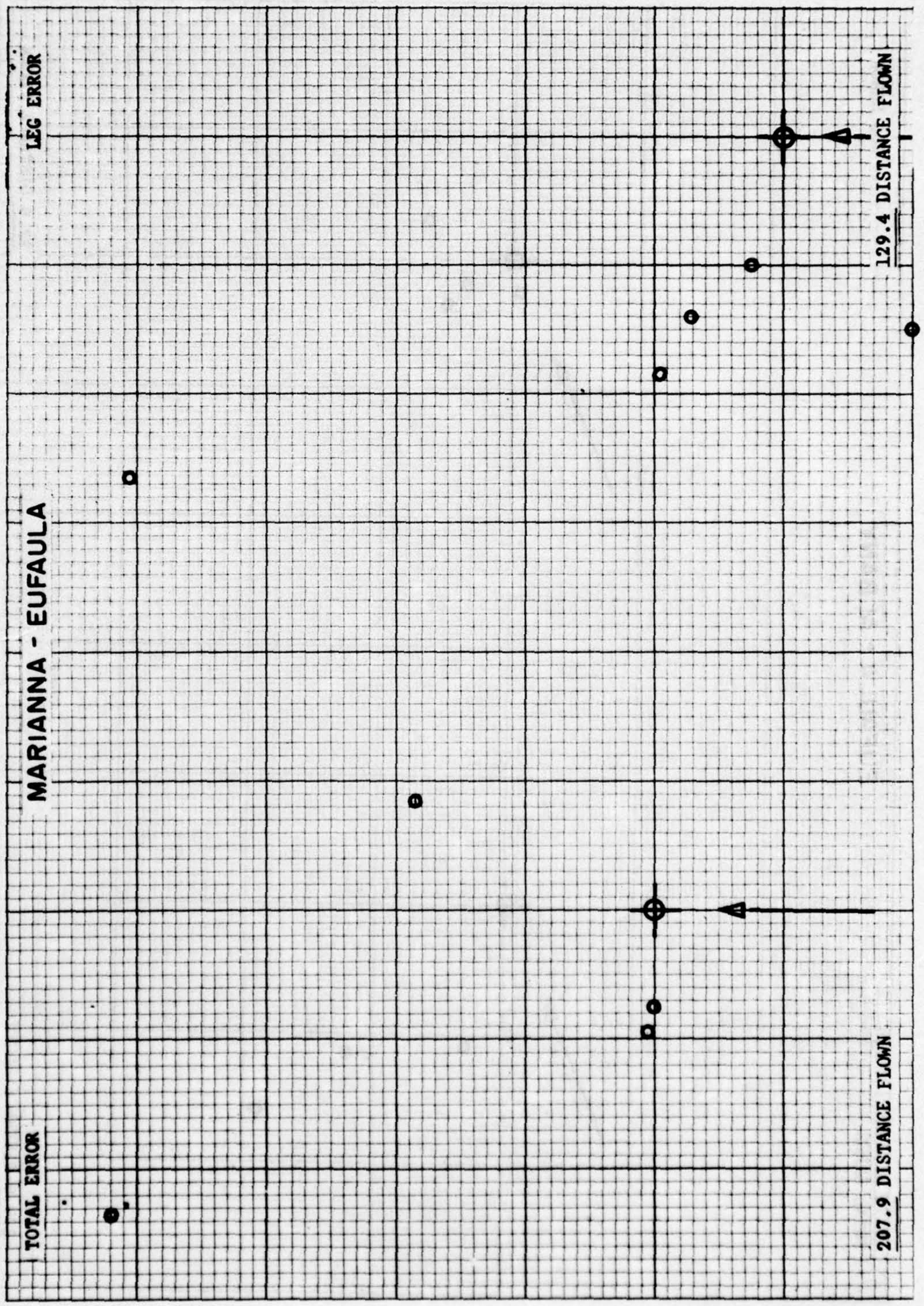
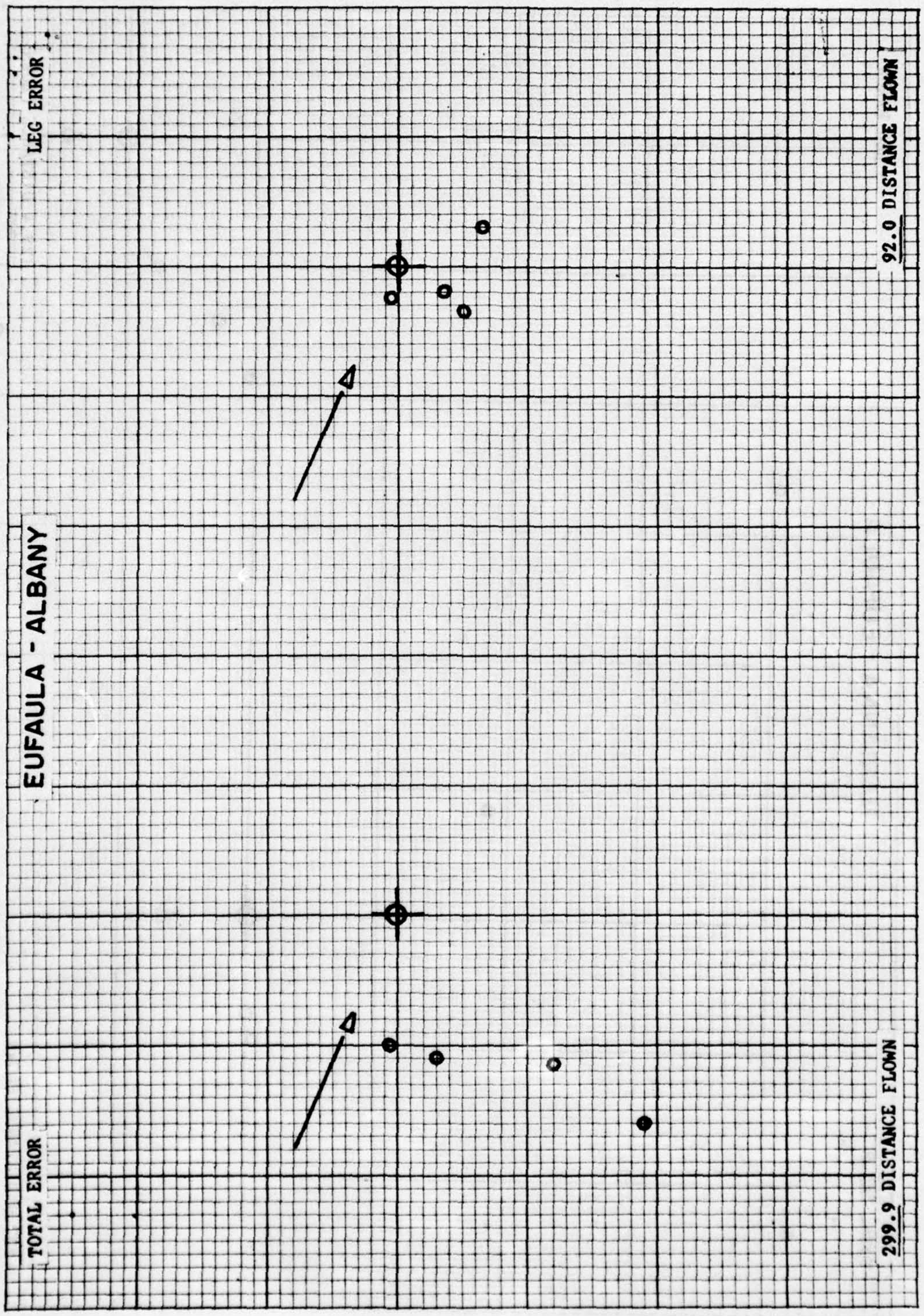
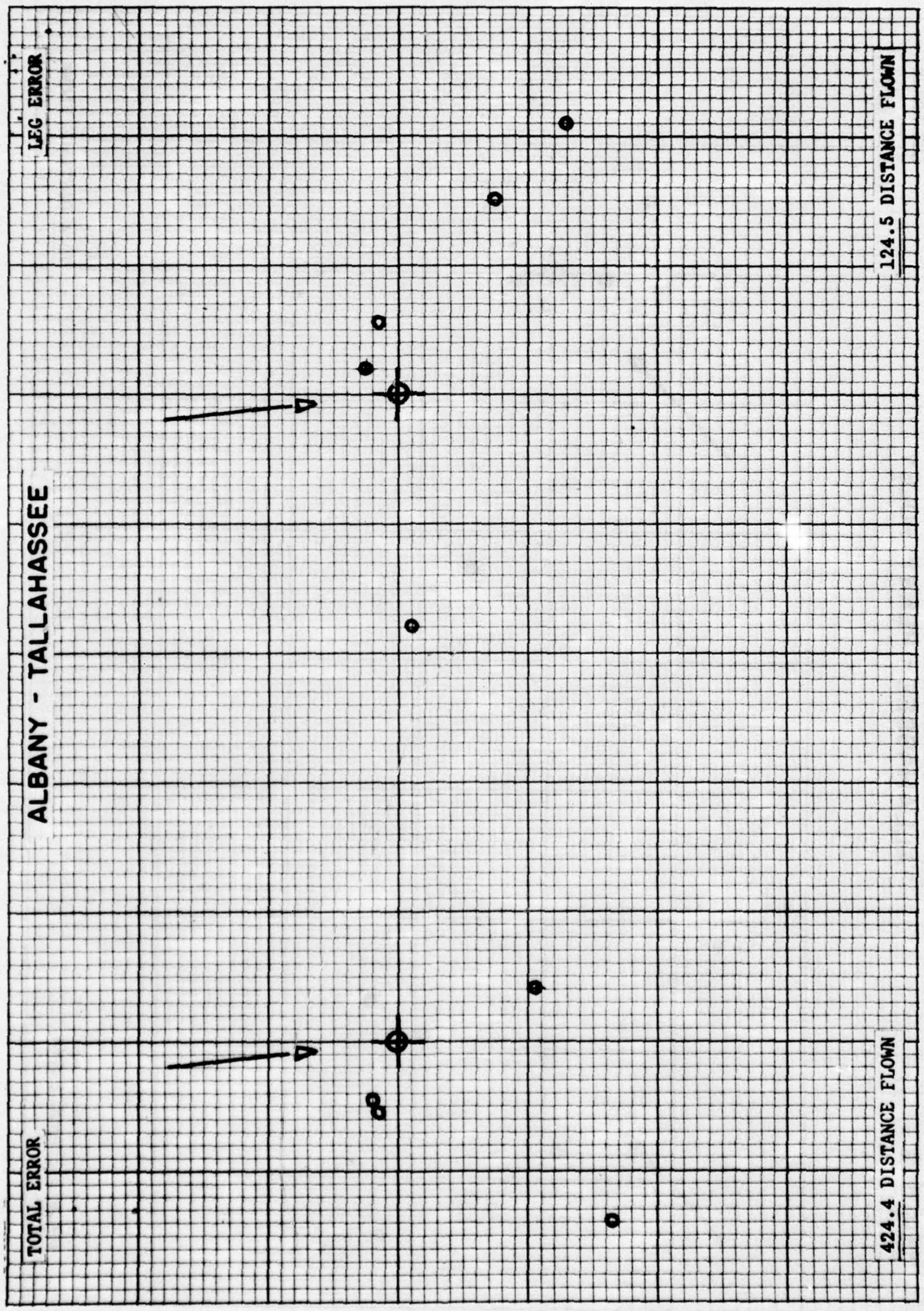

CAIRNS - MARIANNA
LEG ERROR
78.5 DISTANCE FLOWN
TOTAL ERROR
78.5 DISTANCE FLOWN


MARIANNA - EUFAULA
LEG ERROR
TOTAL ERROR
129.4 DISTANCE FLOWN
207.9 DISTANCE FLOWN


EUFAULA - ALBANY
LEG ERROR
92.0 DISTANCE FLOWN
TOTAL ERROR
299.9 DISTANCE FLOWN



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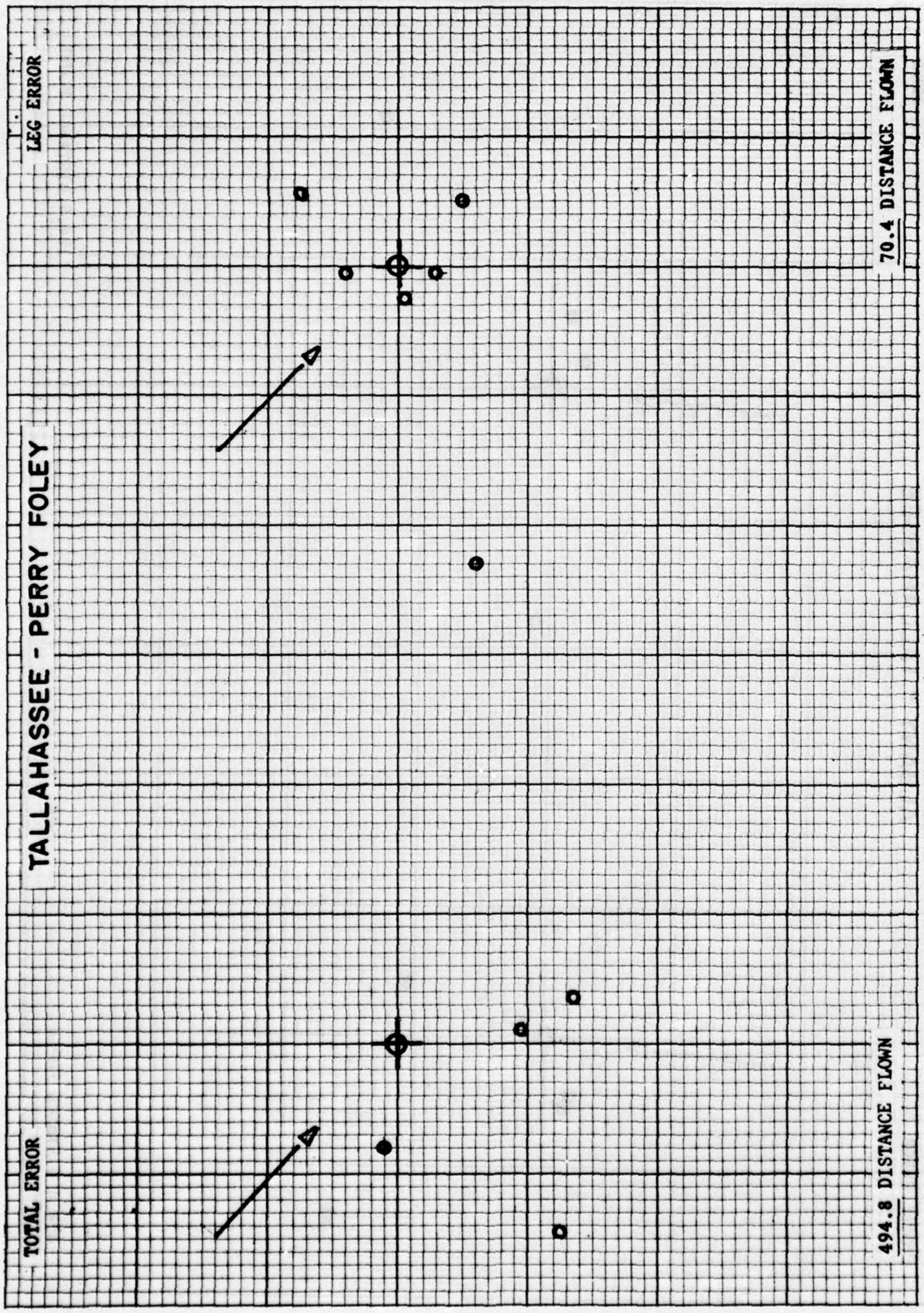
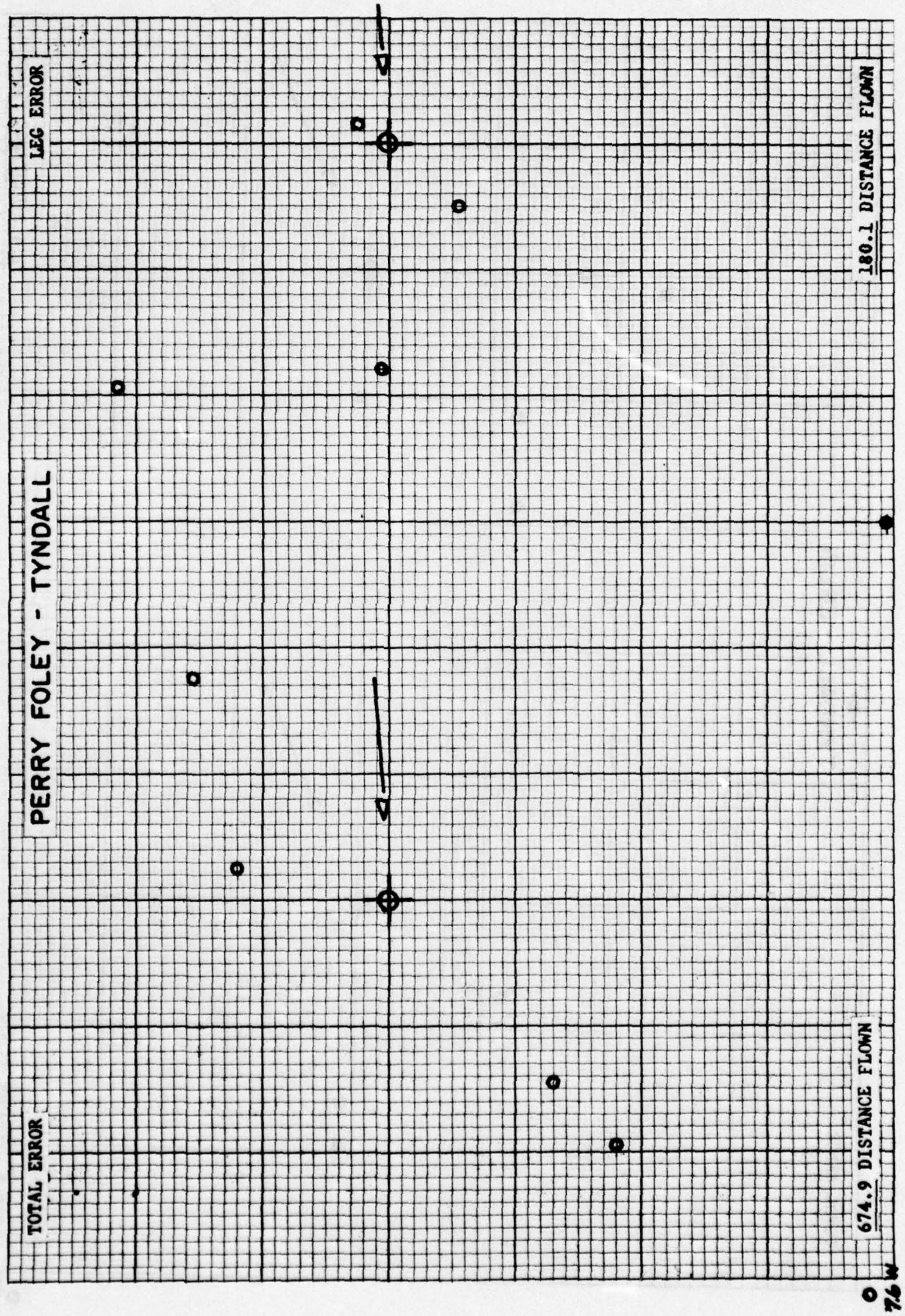
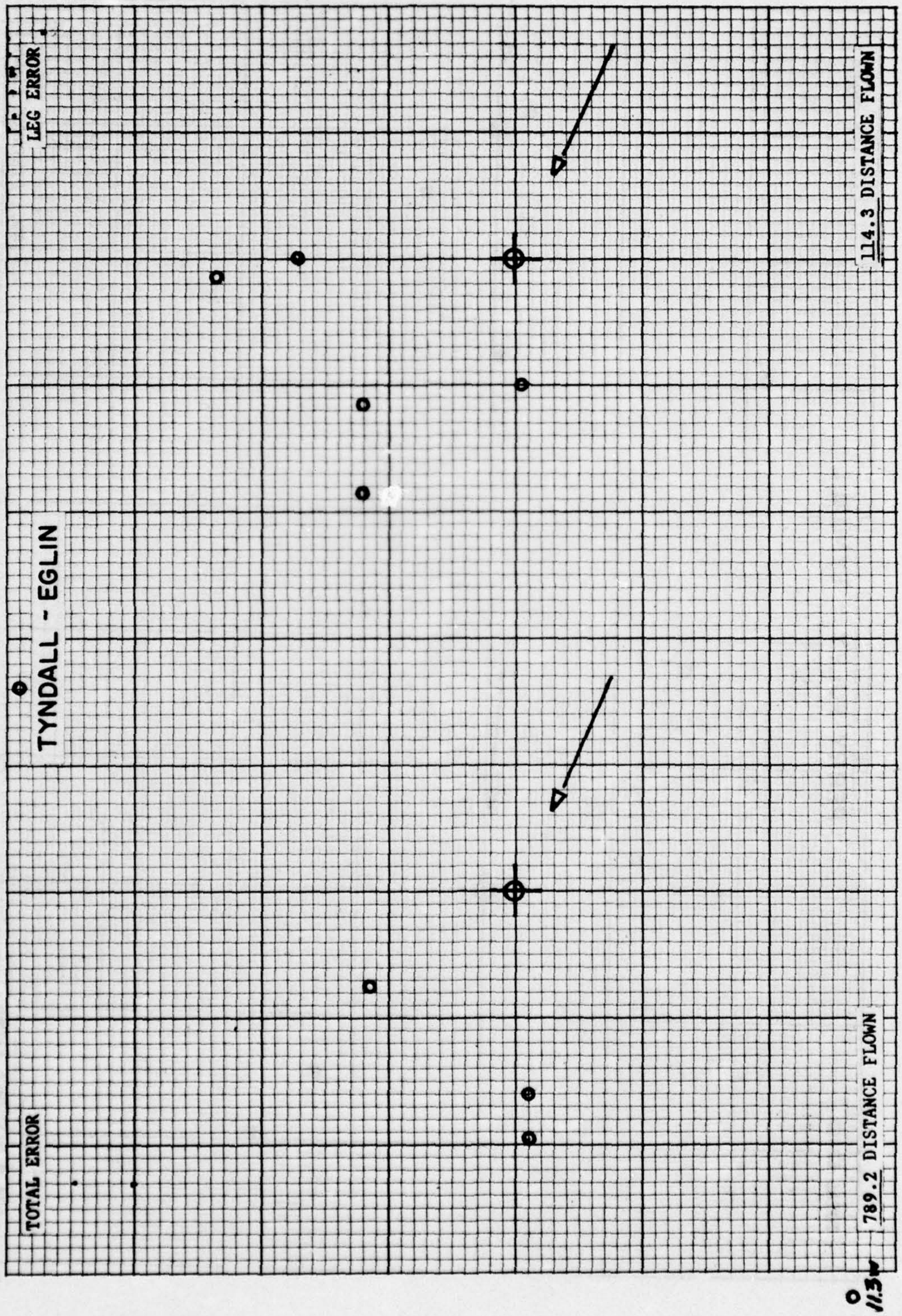
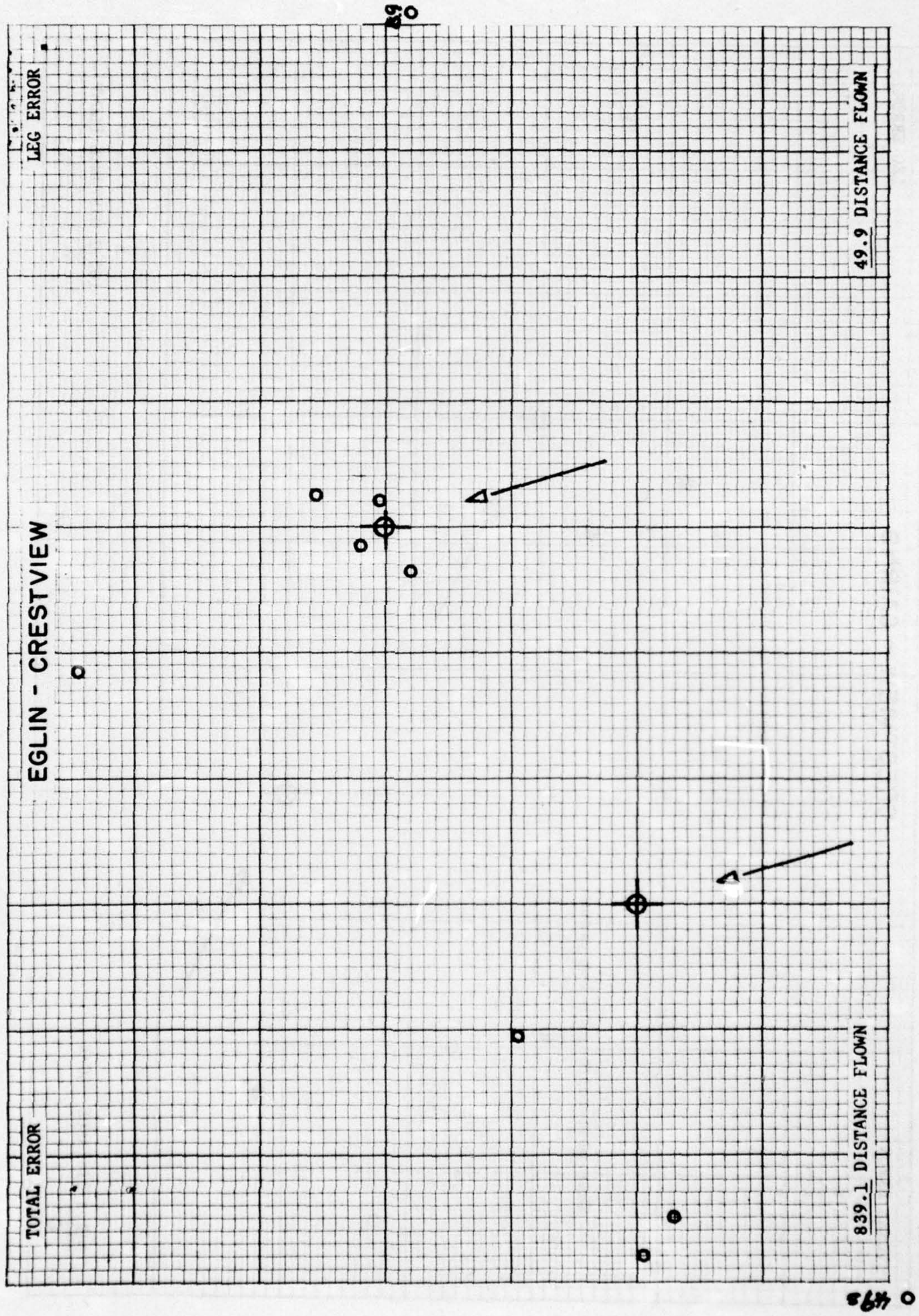
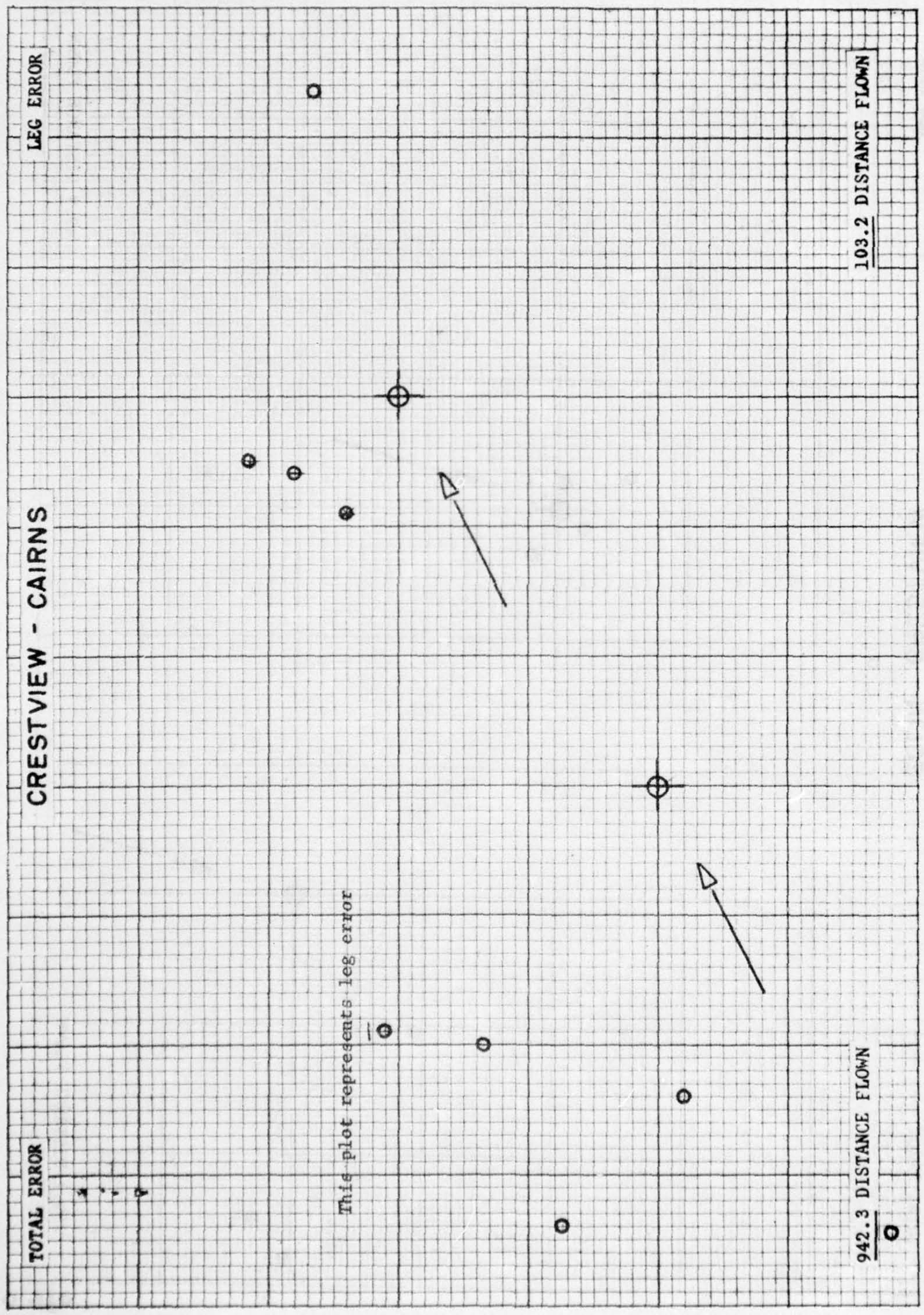

TALLAHASSEE - PERRY FOLEY
LEG ERROR
70.4 DISTANCE FLOWN
TOTAL ERROR
494.8 DISTANCE FLOWN


PERRY FOLEY - TYNDALL
LEG ERROR
180.1 DISTANCE FLOWN
TOTAL ERROR
674.9 DISTANCE FLOWN
0
7.6 W



LEG ERROR
114.3 DISTANCE FLOWN
TYNDALL - EGLIN
TOTAL ERROR
789.2 DISTANCE FLOWN
11.3


EGLIN - CRESTVIEW
LEG ERROR
49.9 DISTANCE FLOWN
TOTAL ERROR
839.1 DISTANCE FLOWN
11.6 W

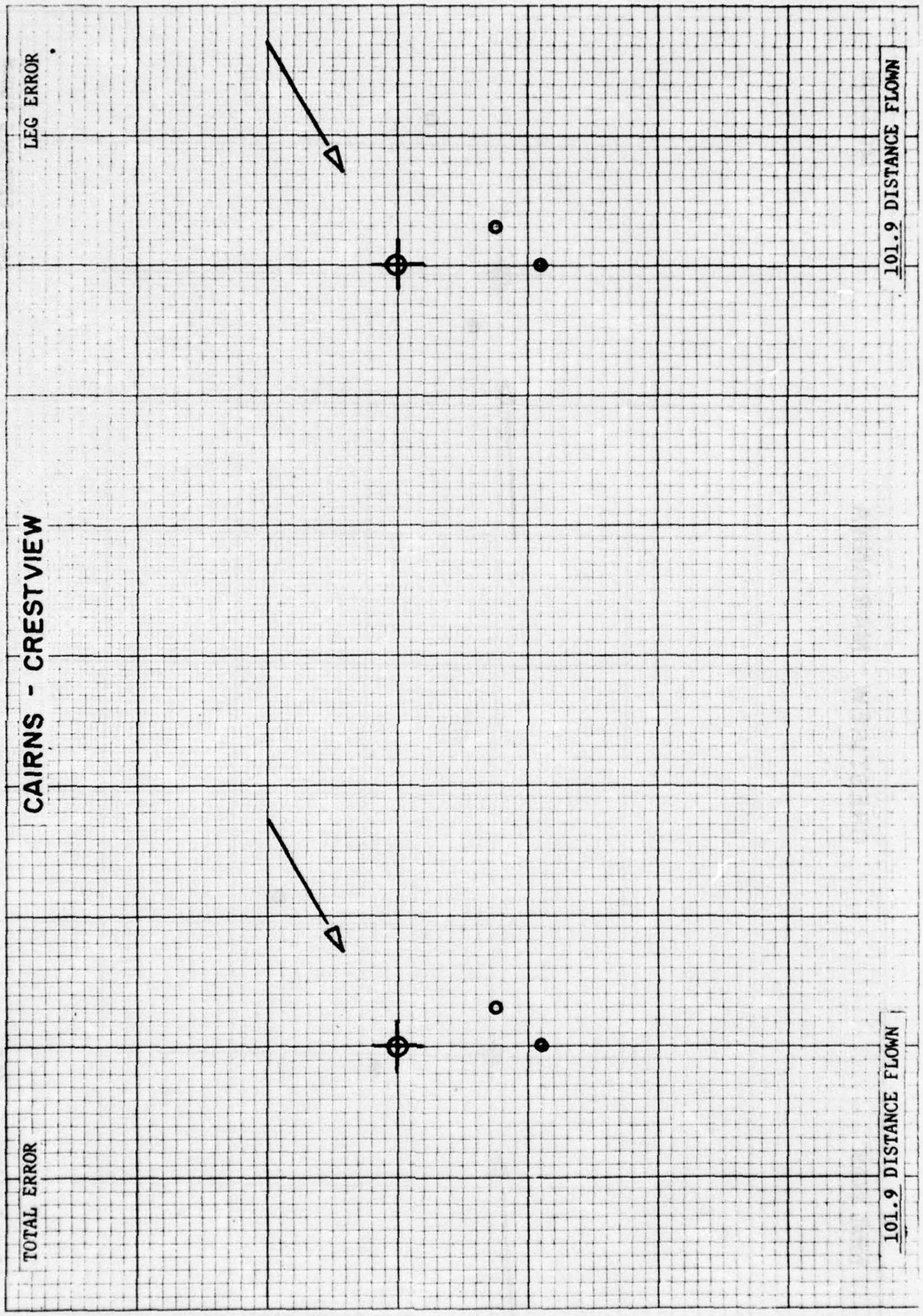

CRESTVIEW - CAIRNS
LEG ERROR
TOTAL ERROR
103.2 DISTANCE FLOWN
942.3 DISTANCE FLOWN
This plot represents leg error

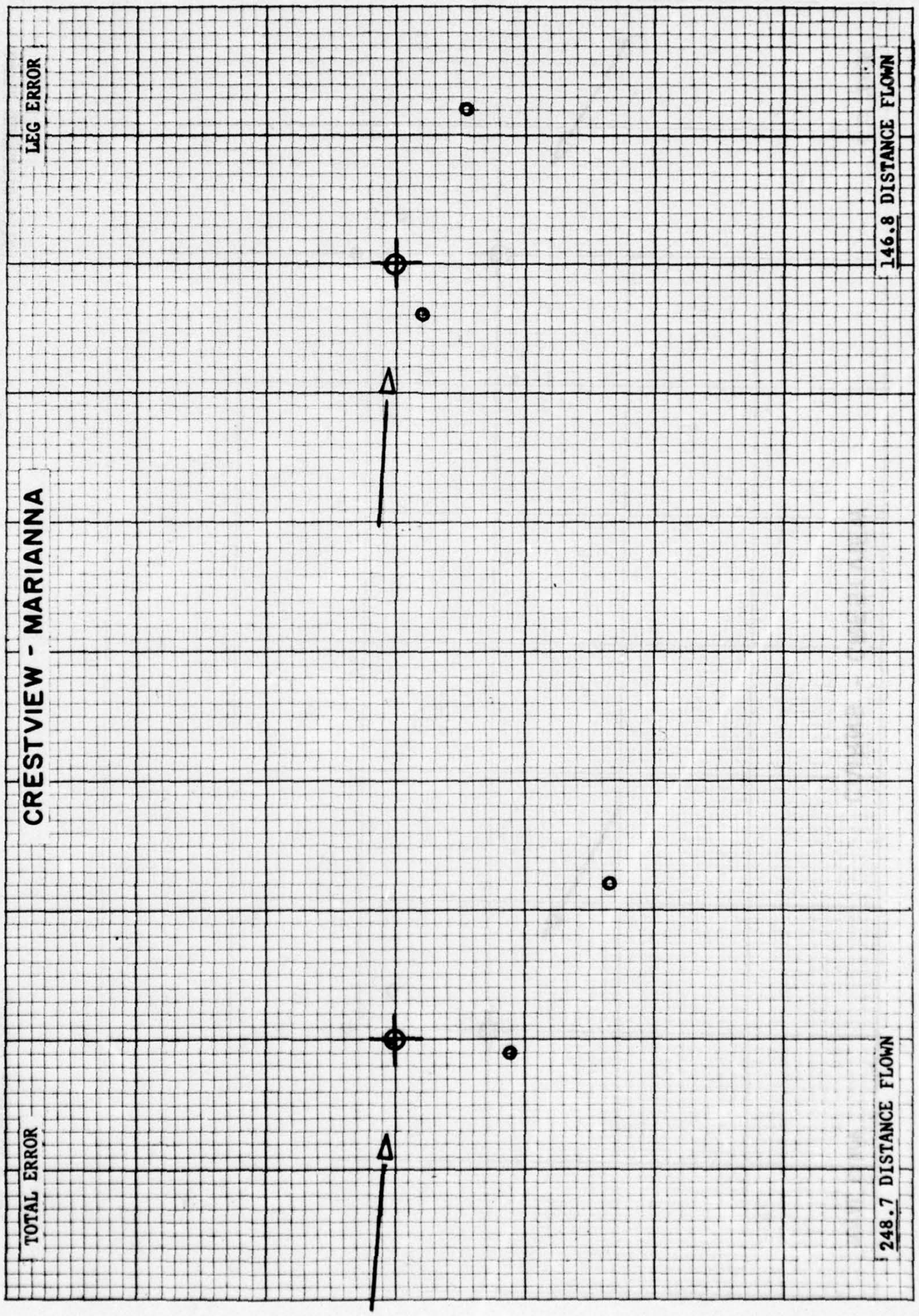
APPENDIX F

Doppler A(RW) Position Error

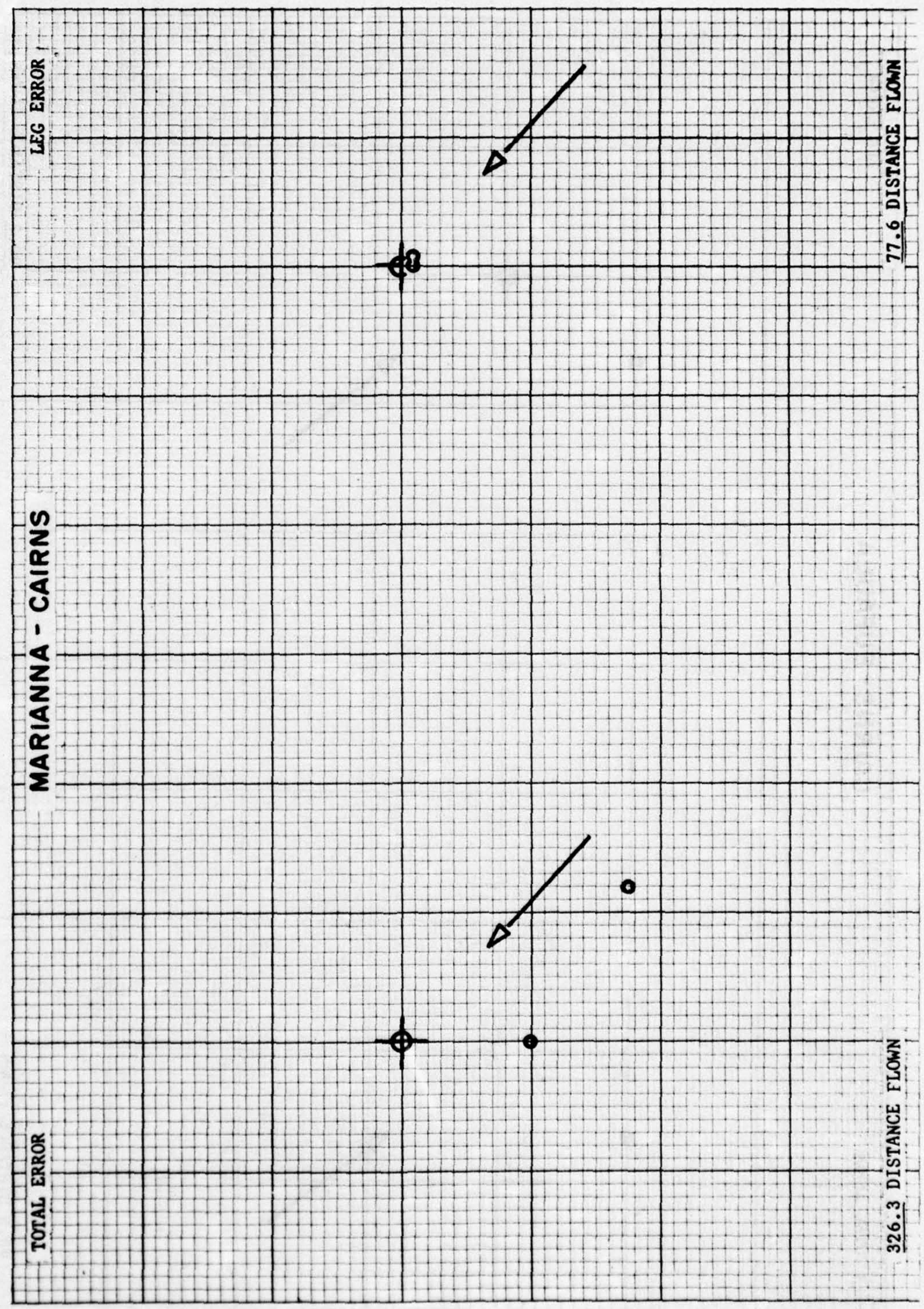
The data recorded in appendix J has been plotted on graphs to provide an immediately available readout of the Doppler navigation system leg error and total position error. These plots represent total system error. This data should not be used for direct comparison purposes without detailed analysis.

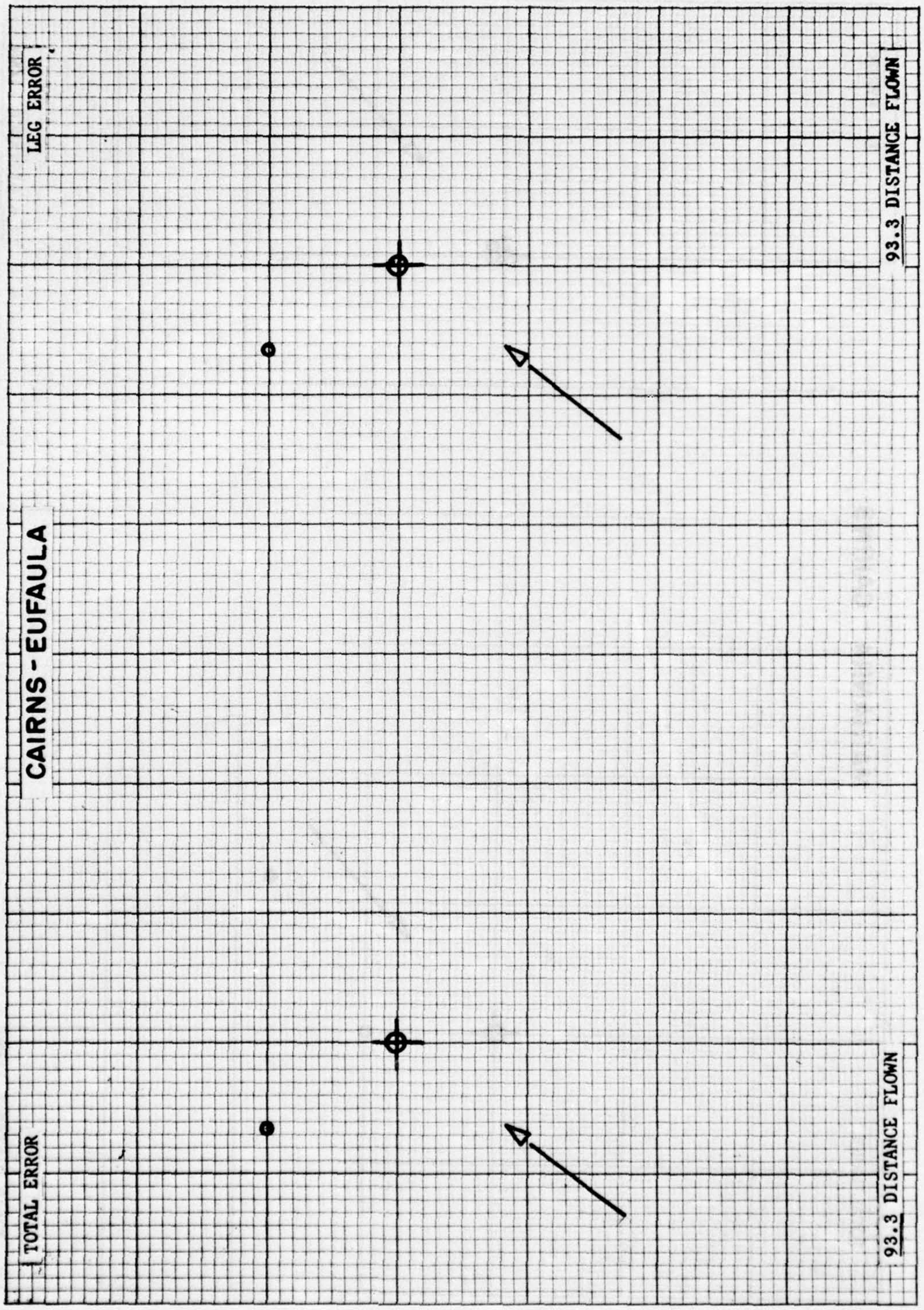
Graph Scale: One Inch = Two Kilometers

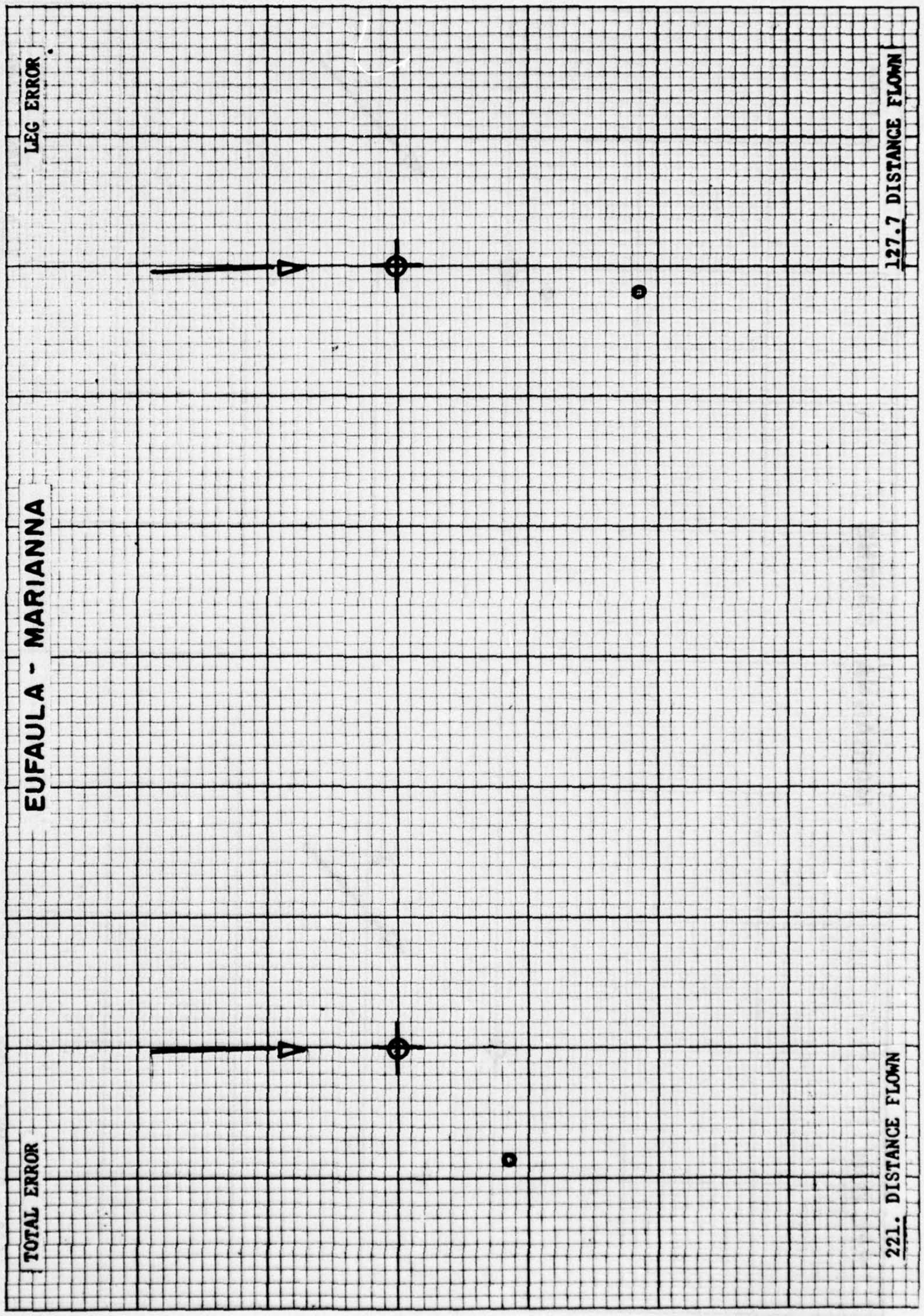

CAIRNS - CRESTVIEW
LEG ERROR
101.9 DISTANCE FLOWN
TOTAL ERROR
101.9 DISTANCE FLOWN

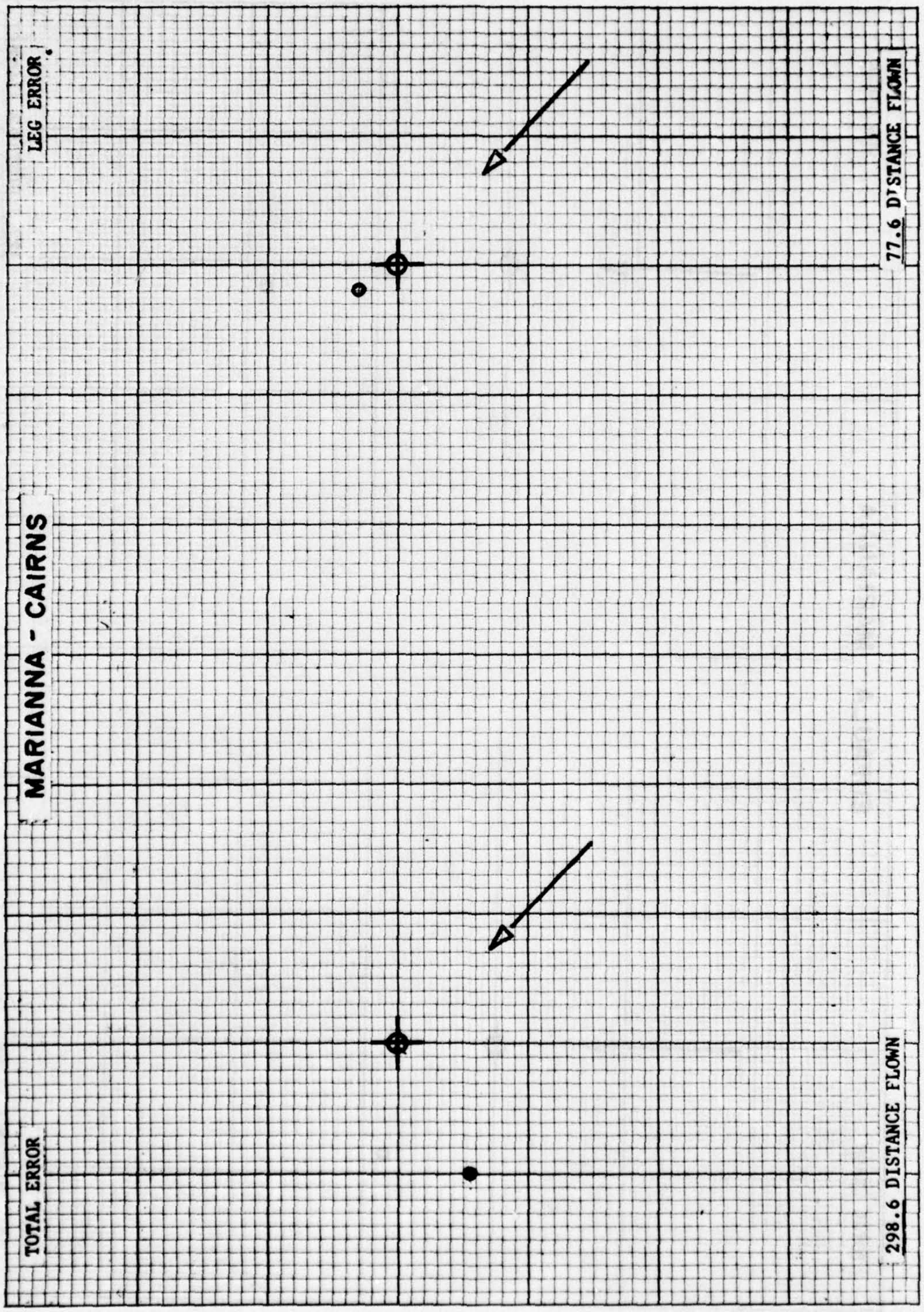


CRESTVIEW - MARIANNA
LEG ERROR
TOTAL ERROR
146.8 DISTANCE FLOWN
248.7 DISTANCE FLOWN


MARIANNA - CAIRNS
LEG ERROR
77.6 DISTANCE FLOWN
TOTAL ERROR
326.3 DISTANCE FLOWN


CAIRNS - EUFAULA
LEG ERROR
93.3 DISTANCE FLOWN
TOTAL ERROR
93.3 DISTANCE FLOWN


EUFAULA - MARIANNA
LEG ERROR
127.7 DISTANCE FLOWN
TOTAL ERROR
221. DISTANCE FLOWN



MARIANNA - CAIRNS
LEG ERROR
77.6 DISTANCE FLOWN
TOTAL ERROR
298.6 DISTANCE FLOWN

APPENDIX G

In-Flight Present Position and Bearing and Distance Data for Doppler A(FW)

This appendix contains bearing, distance, and coordinate values used to program the Doppler computer, as well as flight data collected during each of the 12 closed course flights. This data has significance to engineering personnel only and should not be used for comparison purposes without detailed analysis.

DISTANCE AND BEARING BETWEEN STATIONS

The material contained in this chart was calculated from latitude and longitude data published by the US Department of Commerce (reference 2). This material was used to program the navigation computer under test.

	Distance Nautical Miles		Distance Kilometers		Bearing	Distance
Cairns	26.526S	48.963W	49.16S	90.74W	241° 33' 61° 33'	55.69
Crestview	25.92 S	7.32 E	48.04S	13.56E	164° 14' 344° 14'	26.94
Eglin	25.33 S	56.26 E	46.95S	104.27E	114° 14' 294° 14'	61.71
Tyndall	5.7 N	97.02 E	10.56N	179.80E	86° 38' 266° 38'	97.19
Perry Foley	26.06 N	27.63 W	48.31N	51.21W	313° 19' 133° 19'	37.99
Tallahassee	66.91 N	6.34 W	123.99N	11.74W	354° 35' 174° 35'	67.21
Albany	20.03 N	45.43 W	37.12N	84.20W	293° 47' 113° 47'	49.65
Eufaula	69.84 S	.313E	129.44S	.58E	179° 44' 359° 44'	69.85
Marianna	28.92 N	30.96 W	53.60N	57.38W	133° 03' 313° 03'	42.37
Cairns						

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DOPPLER A(FW) FLIGHT DATA

This chart contains position and bearing/distance data recorded at each of the nine destinations on the fixed-wing course (figure 31).

Flight #	1	2	3	4	5	6
Marianna	27.9S	28.0S	28.6S	28.6S	28.5S	28.5S
	32.1E	32.1E	32.3E	31.5E	31.6E	31.1E
	132.°	133.°	134.°	135.°	135.°	134.°
	42.8	42.	41.6	42.3	41.8	42.4
Eufaula	41.8N	41.9N	42.0N	41.1N	41.3N	41.0N
	28.5E	29.6E	27.9E	28.7E	28.7E	29.1E
	358.°	358.°	358.°	358.°	358.°	358.°
	70.	70.	69.5	70.8	70.5	70.7
Albany	24.1N	23.5N	25.4N	22.8N	23.6N	22.4N
	75.2E	76.0E	74.7E	75.0E	75.3E	75.0E
	113.°	115.°	114.°	114.°	114.°	114.°
	52.5	51.2	52.6	52.	51.6	51.7
Tallahassee	42.5S	42.9S	40.4S	43.4S	42.7S	44.0S
	83.8E	85.6E	85.6E	83.7E	84.6E	82.7E
	172.°	175.°	175.°	174.°	175.°	175.°
	71.2	71.	79.	70.	71.	69.9
Perry Foley	67.2S	67.6S	63.8S	68.4S	68.1S	69.8S
	112.9E	114.8E	115.7E	112.1E	113.2E	110.2E
	135.°	140.°	143.°	137.°	139.°	135.°
	40.6	37.8	39.9	39.	38.6	39.4
Tyndall	73.1S	75.2S	72.6S	76.0S	75.1S	76.7S
	15.7E	17.6E	19.0E	14.9E	15.8E	13.3E
	262.°	264.°	260.°	265.°	264.°	265.°
	100.8	105.7	105.5	101.6	102.7	99.7
Eglin	47.3S	50.0S	48.0S	51.5S	50.2S	51.7S
	40.0W	38.6W	37.7W	42.6W	41.6W	43.6W
	289.°	290.°	287.°	290.°	290.°	292.°
	62.	66.3	66.5	63.5	64.2	62.2
Crestview	21.3S	24.3S	22.3S	25.8S	24.6S	26.1S
	47.6W	46.7W	45.9W	50.7W	49.6W	51.3W
	335.°	332.°	330.°	342.°	339.°	343.°
	22.8	26.2	25.4	26.7	45.8	26.6
Cairns	05.0N	02.6N	05.7N	02.2N	02.9N	00.7N
	01.5E	02.2E	02.3E	02.6W	01.0W	02.7W
	066.°	061.°	064.°	062.°	064.°	064.°
	53.3	53.5	52.	57.8	56.4	58.5

DOPPLER A(FW) FLIGHT DATA

This chart contains position and bearing/distance data recorded at each of the nine destinations on the fixed-wing course (figure 31).

Flight #	1	2	3	4	5	6
Crestview	27.0S	27.6S	27.2S	27.5S	26.9S	27.6S
	48.2W	49.0W	48.8W	49.0W	49.1W	48.5W
	241.°	241.°	241.°	240.°	241.°	241.°
	56.75	56.25	56.2	53.	56.	56.3
Eglin	53.4S	53.4S	52.9S	53.2S	53.3S	53.4S
	41.0W	41.5W	41.5W	41.0W	42.2W	41.4W
	165.°	162.°	165.°	160.°	164.°	165.°
	26.0	26.25	27.6	16.	26.8	26.5
Tyndall	79.8S	80.4S	78.8S	79.2S	79.5S	78.9S
	14.4E	14.2E	14.4E	14.7E	14.4E	16.2E
	115.0°	112.°	164.°	114.°	114.°	114.°
	61.3	61.8	62.2	52.	63.0	61.5
Perry Foley	76.0S	76.6S	75.7S	74.6S	74.9S	73.4S
	111.6E	111.8E	111.5E	111.6E	111.7E	113.7E
	85.°	85.°	85.°	85.°	85.°	85.°
	98.8	98.2	98.7	94.	98.6	96.8
Tallahassee	48.6S	50.3S	49.1S	49.3S	48.2S	47.2S
	85.4E	84.4E	84.8E	83.8E	85.0E	86.4E
	315.°	315.°	315.°	312.°	315.°	311.°
	42.5	42.9	42.	42.	41.6	42.
Albany	16.8N	16.4N	17.5N	16.5N	18.6N	19.2N
	78.5E	76.7E	78.1E	76.6E	78.6E	79.0E
	357.°	353.°	353.°	355.°	351.°	351.°
	73.	73.	72.	64.	71.	70.4
Eufaula	37.6N	35.8N	37.0N	35.7N	38.7N	38.9N
	33.0E	30.7E	31.8E	30.0E	33.0E	33.5E
	296.°	298.°	285.°	297.°	294.°	294.°
	54.	53.2	54.	51.	53.8	53.9
Marianna	32.0S	34.3S	33.0S	32.8S	31.1S	30.4S
	32.8E	32.1E	32.2E	33.2E	32.3E	33.8E
	264.°	180.°	180.°	179.°	180.°	181.°
	66.8	65.4	66.8	60.	68.7	68.7
Cairns	4.0S	6.4S	4.5S	5.4S	2.7S	2.5S
	2.3E	.3E	1.3E	.9E	1.4E	2.4E
	312.°	315.°	315.°	316.°	312.°	311.°
	46.7	47.6	47.	48.	45.5	46.2

APPENDIX H

In-Flight Present Position and Bearing and Distance Data for Doppler B

This appendix contains bearing, distance, and coordinate values used to program the Doppler computer, as well as flight data collected during each of the 12 closed course flights. This data has significance to engineering personnel only and should not be used for comparison purposes without detailed analysis.

DISTANCE AND BEARING BETWEEN STATIONS

The material contained in this chart was calculated from latitude and longitude data published by the US Department of Commerce (reference 2). This material was used to program the navigation computer under test.

	Distance Nautical Miles		Distance Kilometers		Bearing	Distance
Cairns						
	26.526S	48.963W	49.16S	90.74W	241° 33' 61° 33'	55.69
Crestview						
	25.92 S	7.32 E	48.04S	13.56E	164° 14' 344° 14'	26.94
Eglin						
	25.33 S	56.26 E	46.95S	104.27E	114° 14' 294° 14'	61.71
Tyndall						
	5.7 N	97.02 E	10.56N	179.80E	86° 38' 266° 38'	97.19
Perry Foley						
	26.06 N	27.63 W	48.31N	51.21W	313° 19' 133° 19'	37.99
Tallahassee						
	66.91 N	6.34 W	123.99N	11.74W	354° 35' 174° 35'	67.21
Albany						
	20.03 N	45.43 W	37.12N	84.20W	293° 47' 113° 47'	49.65
Eufaula						
	69.84 S	.313E	129.44S	.58E	179° 44' 359° 44'	69.85
Marianna						
	28.92 N	30.96W	53.60N	57.38W	133° 03' 313° 03'	42.37
Cairns						

DOPPLER B FLIGHT DATA

This chart contains position and bearing/distance data recorded at each of the nine destinations on the fixed-wing course (figure 31).

Flight #	1	2	3	4	5	6
Marianna	54.3S 58.0E 132. ° 42. NM	54.3S 58.5E 131. °	55.3S 57.9E 130. ° 41.5 NM	54.5S 58.4E 130. °	54.7S 58.3E	53.5S 59.5E 130. ° 41.5 NM
Eufaula	74.8N 56.4E 355. ° 69.5 NM	76.4N 56.9E 354. °	75.6N 56.3E 353. ° 69.0 NM	76.6N 56.4E 354. °	76.0N 56.1E	77.3N 57.1E 355. ° 70. NM
Albany	37.0N 141.9E 110. ° 49.3 NM	39.2N 143. E 114. °	37.8N 142.3E 113. ° 49. NM	38.8N 142.7E 115. °	37.5N 142.0E	39.8N 143.1E 113. ° 49.2 NM
Tallahassee	88.1S 155.0E 172. ° 65.5 NM	86.4S 157. E 175. ° 65. NM	88.3S 155.5E 175. ° 65. NM	87.4S 156.5E 175. ° 66. NM	89.0S 154.1E	86.2S 158. E 176. ° 67.5 NM
Perry Foley	137.1S 206.8E 130. ° 36.5 NM	135.4S 208.9E 133. ° 37.5 NM	138.0 207.6 130.° 36. NM	137.2S 208.5E 132. ° 33. NM	139.9S 205.5E	135.1S 210.8E 133. ° 35. NM
Tyndall	148.4S 24.8E 265. ° 96.5 NM	147.6S 27.0E 270. ° 98. NM	149.8S 24.4E 270. ° 97.5 NM	149.8S 25.0E 270. ° 98. NM	152.6S 23.0E	148.1S 27.9E 269. ° 100.6 NM
Eglin	102.5S 78.7W 293. ° 63.5 NM	104.2S 73.6W 296. ° 63. NM	104.9S 82.6W 296. ° 63. NM	103.9S 81.6W 296. ° 63. NM	107.6S 83.9W	101.7S 71.2W 292. ° 65. NM
Crestview	54.0S 93.2W 342. ° 30.4 NM	55.7S 87.7W 337. ° 31. NM	55.8S 97.3W 347. ° 28. NM	55.4S 96.2W 347. ° 28. NM	58.6S 98.6W	53.4S 90.3W 341. ° 31. NM
Cairns	4.2S 0. W 56. ° 56.5 NM	7.1S 5.6E 55. ° 54.5 NM	6.8S 3.8W 58. ° 59.5 NM	5.9S 3.1W 57. ° 57. NM	10.9S 4.5W	5.0S 2.9E 56. ° 55. NM

DOPPLER B FLIGHT DATA

This chart contains position and bearing/distance data recorded at each of the nine destinations on the fixed-wing course (figure 31).

Flight #	1	2	3	4	5	6
Crestview	50.7S	50.S	51.S	50.2	44.2S	49.8S
	94.5W	93.4W	93.8W	92.9W	81.3W	92.0W
	239. °	240. °	240. °	239. °	238. °	238. °
	53. NM	55. NM	54. NM	54. NM	54.4 NM	54.5 NM
Eglin	99.3S	97.8S	99.2S	99.S	92.6S	98.3S
	81.1W	79.7W	79.8W	79.5W	67.2W	77.6W
	157. °	157. °	156. °	156. °	174. °	160. °
	26. NM	27. NM	26. NM	26. NM	28.5 NM	26.4 NM
Tyndall	147.4S	147.2S	148.6S	146.6	137.3S	146.S
	21.0E	22.6E	24.6E	23.7E	39.7E	27.5E
	108. °	108. °	106. °	108. °	115. °	110. °
	63. NM	62. NM	62.5 NM	62. NM	58.5 NM	62.5 NM
Perry Foley	141.4S	142.7S	142.8S	140.4S	129.6S	139.1S
	202.9E	203.6E	207.7E	205.2E	222.2E	209.7E
	82. °	81. °	82. °	82. °	86. °	84. °
	99. NM	99. NM	99. NM	98. NM	90.6 NM	97. NM
Tallahassee	91.0S	91.9S	93.5S	91.2S	79.6S	89.8S
	152.1E	153.4E	156.3E	154.1E	170.2E	157.3E
	316. °	315. °	312. °	311. °	302. °	312. °
	39.9 NM	40.5 NM	42. NM	40. NM	42.3 NM	40.8 NM
Albany	33.4N	34.2N	32.5N	34.7N	45.5N	35.8N
	142.4E	142.6E	145.5E	142.3E	155.9E	146.3E
	355. °	356. °	354. °	355. °	346. °	352. °
	69. NM	71. NM	69. NM	69. NM	66. NM	70.5 NM
Eufaula	71.5N	70.7N	70.6N	72.2N	81.9N	73.3N
	57.0E	54.3E	60.5E	56.5E	69.2E	60.3E
	295. °	292. °	296. °	293. °	286. °	294. °
	49. NM	49.5 NM	50.3 NM	49.5 NM	54. NM	51.5 NM
Marianna	58.8S	59.8S	60.1S	58.4S	48.8S	57.5S
	56.2E	56.2	59.8E	57.0E	71.6E	62.2E
	175. °	174. °	175. °	174. °	179. °	178. °
	67. NM	65.5 NM	66. NM	66.5 NM	72.4 NM	67.5 NM
Cairns	5.3S	5.3S	6.9S	4.9S	3.2N	4.1S
	1.7E	2.6W	2.7E	1.6W	11.2E	2.9E
	315. °	329. °	318. °	320. °	300. °	312. °
	43. NM	45. NM	45.5 NM	43. NM	46.5 NM	45. NM

APPENDIX I

In-Flight Present Position and Bearing and Distance Data for Doppler C(FW)

This appendix contains bearing, distance, and coordinate values used to program the Doppler computer, as well as flight data collected during each of the 12 closed course flights. This data has significance to engineering personnel only and should not be used for comparison purposes without detailed analysis.

DISTANCE AND BEARING BETWEEN STATIONS

The material contained in this chart was calculated from latitude and longitude data published by the US Department of Commerce (reference 2). This material was used to program the navigation computer under test.

Station	Distance Nautical Miles		Distance Kilometers		Bearing	Distance
Cairns						
	26.526S	48.963W	49.16S	90.74W	241° 33' 61° 33'	55.69
Crestview						
	25.92 S	7.32 E	48.04S	13.56E	164° 14' 344° 14'	26.94
Eglin						
	25.33 S	56.26 E	46.95S	104.27E	114° 14' 294° 14'	61.71
Tyndall						
	5.7 N	97.02 E	10.56N	179.80E	86° 38' 266° 38'	97.19
Perry Foley						
	26.06 N	27.63 W	48.31N	51.21W	313° 19' 133° 19'	37.99
Tallahassee						
	66.91 N	6.34 W	123.99N	11.74W	354° 35' 174° 35'	67.21
Albany						
	20.03 N	45.43 W	37.12N	84.20W	293° 47' 113° 47'	49.65
Eufaula						
	69.84 S	.313E	129.44S	.58E	179° 44' 359° 44'	69.85
Marianna						
	28.92 S	30.96 E	53.60S	57.38E	133° 03' 313° 03'	42.37
Cairns						

DOPPLER C(FW) FLIGHT DATA

This chart contains position and bearing/distance data recorded at each of the nine destinations on the fixed-wing course (figure 31).

Flight #	1	2	3	4	5	6
Marianna	054.7S	053.0S	053.5S	056.1S	053.8S	052.6S
	057.4E	057.0E	057.5E	052.6E	057.5E	057.4E
	136.°	134.°	135.°	134.°	137.°	137.°
	43. NM	45. NM	43. NM	45. NM	45. NM	60. NM
Eufaula	074.9W	075.7N	078.6N	072.1N	075.8N	067.4N
	059.9E	058.6E	059.3E	055.1E	058.3E	061.5E
	360.°	360.°	121.°	360.°	360.°	360.°
	63. NM	70. NM	50. NM	70. NM	70. NM	70. NM
Albany	043.7N	039.3N	042.5W	036.3	038.6N	038.7W
	147.5E	143.2E	144.2E	138.7	143.0E	141.0E
	122.°	120.°	121.°	118.°	120.°	120.°
	49. NM	50. NM	50. NM	49. NM	52. NM	50. NM
Tallahassee	079.6S	083.2S	082.0S	085.1S	085.7S	085.6S
	166.2E	151.9E	155.5E	146.3E	153.6E	153.8E
	176.°	176.°	176.°	178.°	179.°	133.°
	70. NM	68. NM	70. NM	66. NM	64. NM	80. NM
Perry Foley	124.8	130.9S	131.1S	132.4S	135.5S	133.8S
	220.9	203.2E	206.8E	196.5E	203.7E	205.5E
	146.°	134.°	138.°	132.°	135.°	133.°
	39. NM	42. NM	41. NM	41. NM	40. NM	--
Tyndall	139.4S	141.6S	140.6S	147.3S	146.6S	136.5S
	054.9E	027.0E	028.0E	020.6E	023.6E	031.7E
	265.°	265.°	268.°	268.°	265.°	260.°
	39. NM	98. NM	100. NM	98. NM	99. NM	95. NM
Eglin	094.8S	097.1S	097.1S	105.1S	099.6S	092.0S
	048.7W	075.0W	076.3W	083.4W	078.7W	068.9W
	290.°	293.°	290.°	296.°	296.°	345.°
	66. NM	62. NM	63. NM	60. NM	61. NM	--
Crestview	047.2	049.2S	048.7S	058.2	051.2S	044.4S
	063.1	088.2	098.8E	097.5	091.6W	082.2W
		345.°	344.°	355.°	349.°	345.°
	38. NM	30. NM	30. NM	25. NM	30. NM	--
Cairns	000.4N	001.6S	000.3N	011.3S	002.8S	003.5W
	292.2E	003.7E	001.7E	005.8W	000.9E	010.0E
	05[illegible].°	061.°	060.°	059.°	063.°	061.°
	42. NM	54. NM	53. NM	45. NM	42. NM	48. NM

DOPPLER C(FW) FLIGHT DATA

This chart contains position and bearing/distance data recorded at each of the nine destinations on the fixed-wing course (figure 31).

Flight #	*1	*2	*3	4	5	6
Crestview	058.1S	060.4S	059.7W	049.0S	049.6S	050.2S
	084.7W	080.6W	085.7W	092.4W	091.3W	091.6W
	240.°	240.°	238.°	236.°	235.°	234.°
	61. NM	60. NM	60. NM	68. NM	60. NM	58. NM
Eglin	103.9S	106.4S	108.8S	096.8S	098.1S	097.8S
	066.0W	062.3W	066.4W	078.9W	078.3W	077.7W
	168.°	166.°	170.°	161.°	164.°	154.°
	21. NM	16.5 NM	22. NM	29. NM	29. NM	28. NM
Tyndall	136.9S	143.25S	144.1S	144.1S	144.05S	143.6S
	036.3E	048.2E	043.7E	026.4E	028.3E	026.7E
	121.°	116.°	116.°	112.°	115.°	118.°
	53. NM	52. NM	53. NM	63. NM	67. NM	70. NM
Perry Foley	113.0S	120.0S	120.7S	135.6S	134.2S	133.4S
	218.9E	228.4E	224.6E	207.4E	210.6E	208.9E
	087.°	090.°	090.°	087.°	090.°	090.°
	126. NM	92. NM	93. NM	96. NM	100. NM	100. NM
Tallahassee	067.3S	072.3S	074.0S	086.2S	084.2S	083.0S
	165.1E	175.2E	171.4E	156.6E	160.0E	157.8E
	300.°	296.°	297.°	313.°	316.°	310.°
	37. NM	43. NM	42. NM	39. NM	39. NM	39. NM
Albany	055.7N	050.9N	049.4N	038.3W	040.5W	042.6N
	147.9E	157.2E	154.2E	146.0E	149.3E	147.5E
	358.°	350.°	355.°	356.°	356.°	359.°
	65. NM	63. NM	42. NM	62. NM	70. NM	68. NM
Eufaula	088.0N	082.5W	081.5W	075.1W	077.7W	080.4W
	062.1E	071.5E	066.9E	060.6E	064.1E	062.3E
	283.°	284.°	289.°	294.°	293.°	290.°
	47. NM	49. NM	48. NM	48. NM	48. NM	49. NM
Marianna	041.0S	045.4S	047.8S	054.6S	051.9S	049.5S
	070.0E	078.8E	074.6E	059.8E	063.2E	062.1E
	180.°	180.°	180.°	179.°	180.°	178.°
	80. NM	70. NM	73. NM	68. NM	73. NM	73. NM
Cairns	007.4N	002.3N	001.7N	000.2S	001.4W	004.7W
	008.9E	019.4E	013.3E	001.8E	004.7E	004.4E
	314.°	302.°	303.°	314.°	311.°	314.°
	44. NM	46. NM	45. NM	42. NM	44. NM	42. NM

* Variation was inserted in reverse

NOTE: Variation was inserted in reverse direction for first three flights of Doppler C(FW) and resulted in incorrect data. The following values were obtained by mathematically rotating the grid reference to correct for this error.

Flight #	1	2	3
Crestview	48.3S 90.6W	51.1S 86.8W	47.8S 91.8W
Eglin	96.1S 77.8W	99.1S 74.5W	99.0S 78.9W
Tyndall	143.0S 19.9E	148.0S 31.2E	146.4S 26.6E
Perry Foley	132.7S 203.8E	138.2S 212.6E	136.4S 208.7E
Tallahassee	84.1S 152.6E	87.6S 162.1E	86.8S 158.2E
Albany	39.7N 142.5E	36.4N 151.2E	37.4N 148.1E
Eufaula	76.9N 58.7E	73.4N 67.7E	75.0N 63.1E
Marianna	52.3S 56.4E	54.7S 66.8E	54.5S 60.5E
Cairns	1.5N 1.0W	0.9S 11.9E	0.3N 3.9E

APPENDIX J

In-Flight Present Position and Bearing and Distance Data for Doppler A(RW)

This appendix contains bearing, distance, and coordinate values used to program the Doppler computer, as well as flight data collected during the three closed course flights made on this system at Fort Rucker, Alabama. This data has significance to engineering personnel only and should not be used for comparison purposes without detailed analysis.

DISTANCE AND BEARING BETWEEN STATIONS

The material contained in this chart was calculated from latitude and longitude data published by the US Department of Commerce (reference 2). This material was used to program the navigation computer under test.

Stations	Distance Nautical Miles		Distance Kilometers		Bearing	Distance
Cairns – Crestview	26.526S	48.963W	49.16S	90.74W	241°33' 61°33'	55.69
Eufaula – Marianna	69.84 S	.313E	129.44S	.58E	179°44' 359°44'	69.85
Marianna – Cairns	28.92 N	30.96 W	53.60N	57.38W	133°03' 313°03'	42.37
Cairns – Eufaula	40.92 N	30.46 E	75.84N	56.45E	36°40' 216°40'	51.01
Crestview – Marianna	2.40 S	80.12 E	4.43S	148.48E	91°43' 271°43'	80.15

FLIGHT DATA - DOPPLER A (RW)

	Flight #1	Flight #2
Crestview	46.5S	47.2S
	89.7W	90.2W
	240.°	242.°
	55.5 NM	56. NM
Marianna	49.8S	51.2S
	54.5E	57.1E
	87.°	92.5°
	81. NM	80.5 NM
Cairns	3.3N	1.8W
	2.2W	.0E
	311.°	312.5°
	41.5 NM	41.5 NM

	Flight #3
Eufaula	72.8N
	57.1E
	37.5°
	51.0 NM
Marianna	51.2S
	58.0E
	180.°
	69.8 NM
Cairns	1.1N
	1.8E
	312.°
	42.3 NM

Note: Distance readouts have been converted to kilometers.

APPENDIX K

In-Flight Present Position Data for Wind Memory Operation of Dopplers A(FW), B, and C(FW)

This appendix contains coordinate values used to program the computer as well as data recorded during flight. This data has significance to engineering personnel only and should not be used for comparison purposes without detailed analysis.

WIND MEMORY OPERATION

STATION COORDINATES

The material contained in this chart was calculated from latitude and longitude data published by the US Department of Commerce (reference 2). This material was used to program the navigation computer under test.

	Distance Nautical Miles		Distance Kilometers	
	N-S	E-W	N-S	E-W
Doppler A (FW)				
Cairns (OMNI)	00	00		
Eufaula	40.9N	30.5E		
Marianna	28.9S	31.0E		
Dopplers B and C (FW)				
Libby AAF (OMNI)			00	00
Douglas			8.6S	63.6E
Cochise			49.2N	55.4E

WIND MEMORY OPERATION FLIGHT DATA

The data contained in this chart represents the navigation computers solution of the location of each station using data stored in the wind memory circuits of the computer.

DOPPLER A (FW)

Eufaula	4.7N 27.7E
Cairns	3.0N 2.1W
Eufaula	42.7N 32.9E
Marianna	26.7S 38.7E
Cairns	3.1N 9.5E

	DOPPLER B	DOPPLER C (FW)
Douglas	8.8S 64.1E	13.5S 66.1E
Cochise	50.3N 54.4E	43.2N 59.8E
Douglas	8.2S 62.9E	8.1S 63.7E
Libby AAF	0.8S 4.2W	0.8S 1.8E

APPENDIX L

COMPARISON WITH MILITARY CHARACTERISTICS

(Classified; presented under separate cover.)

APPENDIX M

COMPASS CALIBRATION

1. The MA-1 compass system and the AN/ASN-43 compass system were utilized as the heading reference systems during the Doppler evaluation. The MA-1 is standard equipment in the OV-1 ( ) airplane. The AN/ASN-43 was installed for use in the UH-19D Helicopter in place of the existing J-2 compass system. Each heading reference system was checked for accuracy and compensated as required. The representative of each manufacturer concurred in the final calibration of the OV-1 ( ) (clean swing) (annexes 1, 2, and 3); the representative for Doppler A (RW) system took exception to the swing as indicated by the deletion (see annex 4). Numerous problems can be expected when attempting to accomplish a compass calibration during field conditions to provide the accuracies required. The facilities available at Fort Rucker to compensate a compass consist of a compass rose (figure 37) surveyed by use of the MC-1 as a standard which was used for a manual swing of the MA-1, and an MC-1 compass calibrator which was used for compensating the AN/ASN-43. (See figure 38 for a type of field installation.)

a. The OV-1 heading systems (MA-1) were calibrated by placing the left wheel on the compass rose turntable. With engines running, the airplane was rotated to each compass compensating point. The accuracy was obtained by optically sighting to surveyed points along an axis perpendicular to a line through the main wheel axles. (See figure 39.)

b. The UH-19D heading system (AN/ASN-43) was initially to be calibrated by use of the compass rose. An acceptable calibration could not be obtained by this means because of the vibration created from the main rotor blades and the lateral flexing of the tail boom which prevented the flux valve from stabilizing to accept a compensation. After 80 man-hours, the attempt was abandoned and a request for assistance was forwarded to US Army Electronics Research and Development Laboratories. This was necessitated because of the lack of familiarity with this new compass system and lack of knowledge on how to operate the MC-1 compass calibrator with this system. The manufacturer of the AN/ASN-43 and the MC-1 subsequently provided a technical representative. The AN/ASN-43 was electronically calibrated by use of the MC-1 after 66 man-hours of effort. Difficulty was encountered even during the electronic calibration because of the flux valve location

in the tail boom. This calibration procedure provided a heading system accuracy of approximately one-half degree. This accuracy is not fully acceptable for use when employing a Doppler system.

2. Initially two MA-1 compass systems were so unstable that they had to be replaced. Subsequently, two of the MA-1 systems were checked to determine whether the compass had lost any accuracy. One had an index shift of approximately 50 minutes and the other had index shifts of approximately 30 minutes. No compensation was completed during the recheck of the system accuracies.

ANNEX 1

The ground calibration of the MA-1 Compass System in OV-1B 625869 was completed on 20 September 1963. It is agreed that this calibration (data provided below) provides the most accurate heading reference system possible with the means available. This accuracy is considered adequate for conduct of Doppler tests.

OV-1B, S/N 625869 MA-1 Compass 29 September 1963

Actual Heading	Clean Swing
00	00°01'
345	345°09'
330	330°06'
315	315°04'
300	299°57'
285	285°09'
270	270°00'
255	254°59'
240	239°55'
225	225°07'
210	210°00'
195	194°58'
180	179°57'
165	165°04'
150	150°05'
135	135°02'
120	120°07'
105	105°07'
90	89°55'
75	75°03'
60	60°00'
45	45°06'
30	30°03'
15	15°07'

/s/ L. Dumas

/s/ James F. Vaughn
Major, SigC

ANNEX 2

The ground calibration of the MA-1 Compass System in OV-1B 625879 was completed on 16 September 1963. It is agreed that this calibration (data provided below) provides the most accurate heading reference system possible with the means available. This accuracy is considered adequate for conduct of Doppler tests.

OV-1B, S/N 625879 MA-1 Compass 16 September 1963

Actual Heading	Clean Swing
0	359°51'
345	345°08'
330	330°
315	315°05'
300	299°55'
285	284°54'
270	270°02'
255	255°08'
240	240°06'
225	224°51'
210	209°57'
195	195°04'
180	180°05'
165	165°03'
150	149°55'
135	135°07'
120	120°02'
105	104°58'
90	89°56'
75	74°57'
60	60°05'
45	44°54'
30	29°56'
15	14°51'

/s/ Wm. P. Hush /s/ V. R. Rogers, Jr.

ANNEX 3

The ground calibration of the MA-1 Compass System in OV-1B 625881 was completed on 10 September 1963. It is agreed that this calibration (data provided below) provides the most accurate heading reference system possible with the means available. This accuracy is considered adequate for conduct of Doppler tests.

OV-1B, S/N 624881 MA-1 Compass 10 September 1963

Actual Heading	Adj	Clean Swing
0	359°50'	360°5'
345	345°10'	345°10'
330	330°5'	329°58'
315	314°57'	315°3'
300	299°55'	299°55'
285	284°55'	285°3'
270	270°5'	269°55'
255	254°58'	254°50'
240	239°55'	240°5'
225	225°2'	225°5'
210	210°8'	210°20'
195	194°55'	195°15'
180	179°54'	179°59'
165	164°55'	165°5'
150	149°50'	150°5'
135	134°55'	135°12'
120	119°57'	119°52'
105	104°55'	105°15'
90	89°59'	90°4'
75	74°56'	74°55'
60		60°
45	45°2'	44°58'
30		30°2'
15	15°2'	15°2'

/s/ Pritro A. Rotondo /s/ V. R. Rogers, Jr.

ANNEX 4

The ground calibration of the AN/ASN-43 (V) Compass System in UH-19C Helicopter 52-7608 was completed on 6 October 1963. This swing was made using the MC-1 Compass Calibrator. ~~It is agreed that this calibration (data provided below) provides the most accurate heading reference system possible with the means available. This accuracy is considered adequate for conduct of Doppler tests.~~

UH-19, S/N 52-7608 — 6 October 1963

Actual Heading	Reading
0	359°48'
15	14°42'
30	29°42'
45	44°44'
60	59°51'
75	74°51'
90	89°48'
105	104°42'
120	119°37'
135	134°37'
150	149°37'
165	164°35'
180	179°45'
195	194°47'
210	209°54'
225	225°04'
240	240°10'
255	255°10'
270	270°10'
285	285°04'
300	299°55'
315	314°45'
330	329°45'
345	344°44'

/s/ Kenneth W. Rhoades
15 Oct'63

/s/ V. R. Rogers, Jr.

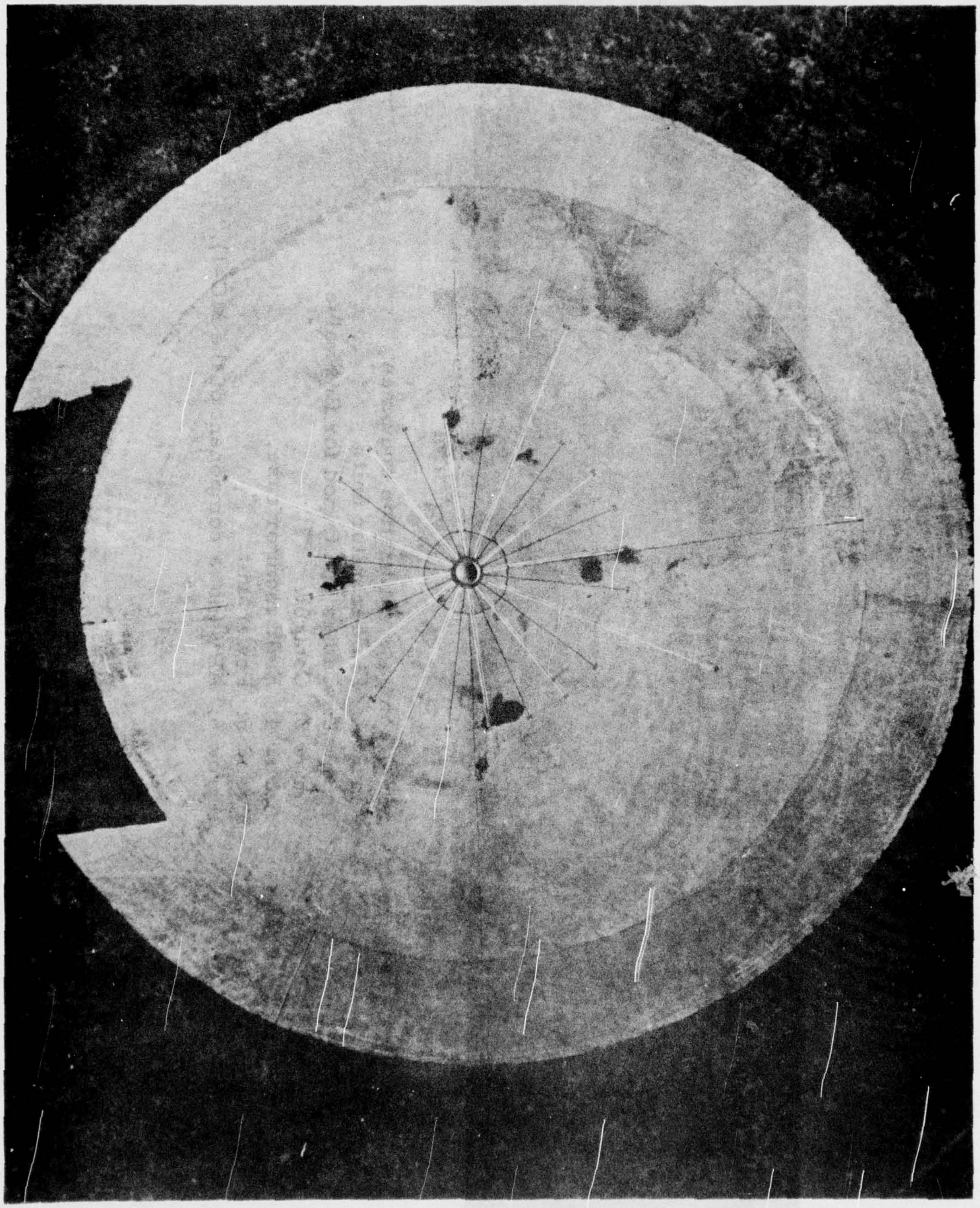

Figure 37. Compass rose.

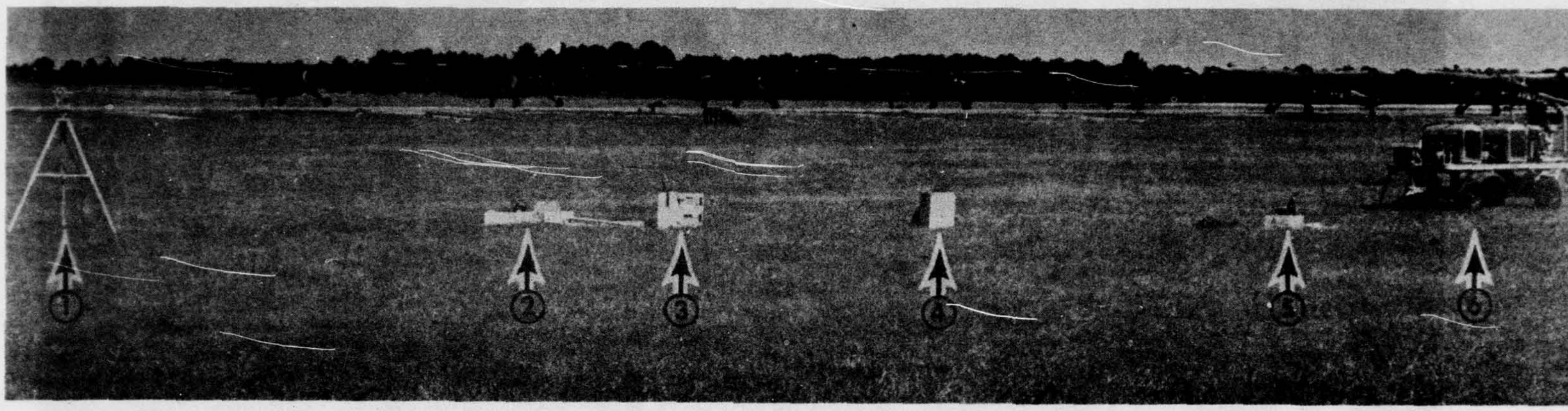

Figure 38. MC-1 compass calibration equipment.
Arrow 1: Field monitor unit.
Arrow 2: Cables and tripod for flux valve.
Arrow 3: Control.
Arrow 4: Field monitor case.
Arrow 5: Power unit.
Arrow 6: APV (not a component of the MC-1).

PROCEDURES USED TO GROUND SWING OV-1( )

1. Position aircraft on rose with left main gear over center of dish.
2. Attach positioning scope to main gear structure over wheel.
3. Position aircraft to magnetic north by rotating aircraft counter-clockwise until the center of both wheel axles lie on the east reference line.
4. Adjust scope until crosshair falls on north index.
5. Rotate aircraft to each of the three other cardinal headings and check alignment of scope.
6. Without touching the scope, rotate the aircraft as necessary to complete compass swing procedure.
7. Positioning accuracy of the above procedures were verified by two methods:
   a. After calibration of the compass system, the scope was moved to the right main gear and the above positioning procedure repeated in a clockwise direction. Position accuracy as measured by a precision compass readout was ± 3 minutes.
   b. With the aircraft on a cardinal heading as positioned by the above procedure, a transit (part of MC-1 compass calibrator) was placed approximately 200 feet from the rose on the cardinal line. Using this line, the bearing to a distant radio tower was established. The transit was then moved along this line until it was possible to sight up the centerline of the aircraft. The transit was then leveled and indexed by sighting on the tower. The magnetic heading of the aircraft was then read from the scale. This value agreed within ± 1 minute of the original reading as established by the above procedure.

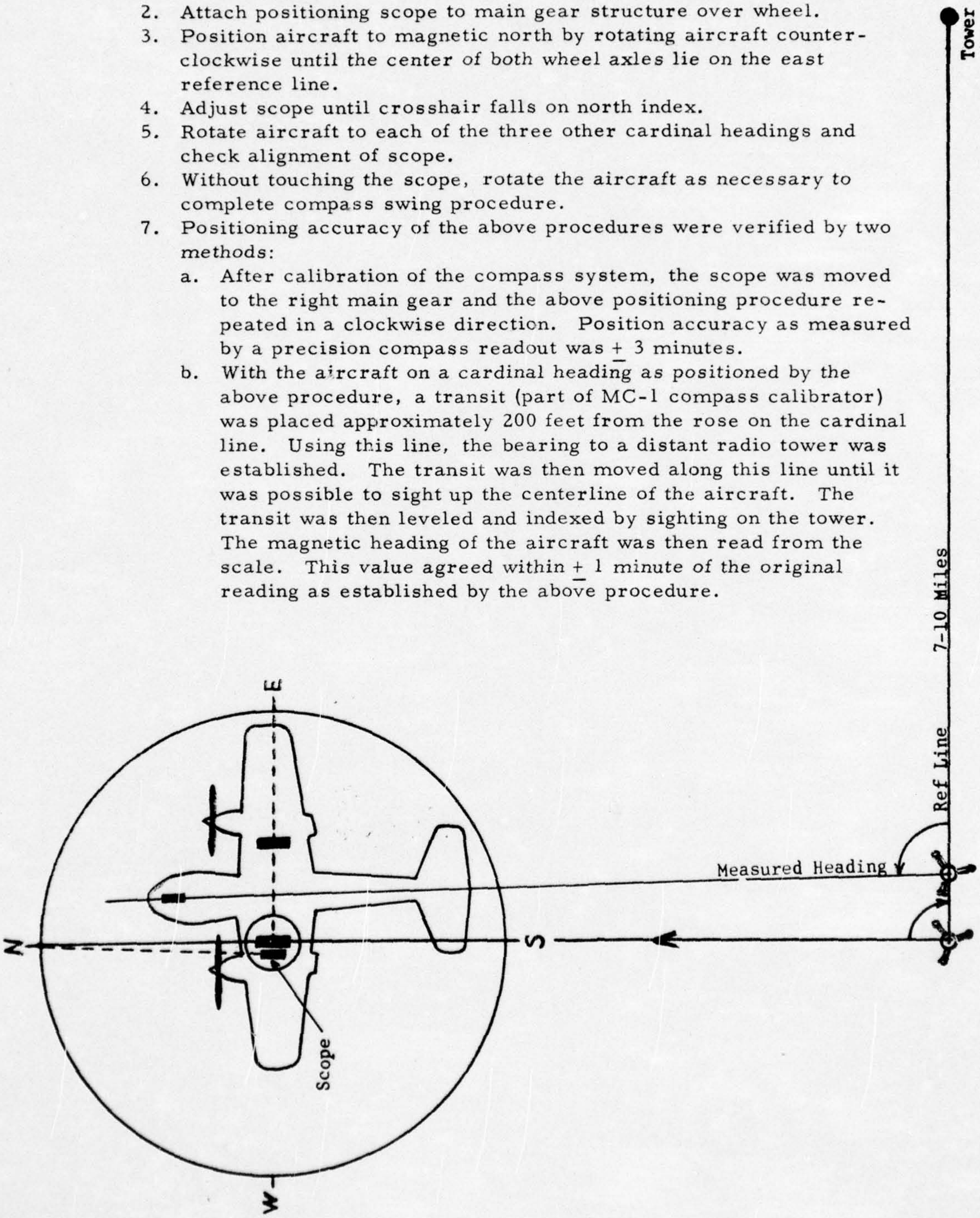

Figure 39

APPENDIX N

Human Factors Evaluation of Off-the-Shelf Airborne Doppler Navigator Systems

US Army Aviation Human Research Unit

13 December 1963

U. S. ARMY AVIATION HUMAN RESEARCH UNIT
U. S. CONTINENTAL ARMY COMMAND
Post Office Box 428
Fort Rucker, Alabama

A field unit of
The George Washington University
Human Resources Research Office
Operating Under Contract With
The Department of the Army
HUMRRO

Telephone 5723
Fort Rucker
13 December 1963

Major James F. Vaughn
U. S. Army Aviation Test Board
Fort Rucker, Alabama

Dear Sir:

Enclosed please find the "Human Factors Evaluation of Off-the-Shelf Airborne Doppler Navigator Systems" report.

Very truly yours,

/s/ Robert H. Wright
/t/ Robert H. Wright, Ph.D.
Research Scientist

RHW:js

Enc.

~~FOR OFFICIAL USE ONLY~~

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U. S. ARMY AVIATION HUMAN RESEARCH UNIT
FORT RUCKER, ALABAMA

Human Factors Evaluation of Off-the-Shelf
Airborne Doppler Navigator Systems

Conclusions

1. The Manufacturer C doppler navigation system appears to be the best designed of the three systems from a human factors standpoint. All three systems have a number of human factors discrepancies which should be corrected before a system is adopted for use in Army aviation.

2. No system provides satisfactory methods or capability for manual correction of position counters while the aircraft is in flight on low altitude tactical missions. For this reason all three systems are considered unacceptable from the human factors standpoint. All three systems will reduce the routine data processing demands made on the pilot, but significant and needed additional improvement in tactical performance could be obtained by a careful redesign of the systems with particular attention given to the functional requirements of Army aviation.

3. The pictorial display will reduce the trackkeeping and information processing requirements currently placed on the operator, and will be of considerable value when major portions of a mission can be flown on one chart. However, the pictorial display, as presently designed and used, will present operator problems in a tactical environment due to poor lighting, preplanning requirements, and demands for attention during flight.

4. The Manufacturer C helicopter hovering indicator is preferable for hover performance in terms of reference sense and display-control response compatibility because it uses the natural "fly-from" reference sense for all indications and does not introduce response incompatibilities.

4.1 The mixing of reference sense and responses to indications as is done on the Manufacturer A hovering indicator is extremely undesirable from the human factors standpoint.

4.2 The use of the Manufacturer C hovering indicator may be expected to introduce serious interference with use of other instrumentation. There appears to be no satisfactory solution to these serious

human factors problems without a complete revision of the Army aircraft instrumentation philosophy.

4.3 The consequences with respect to transfer to other instruments (of using the "fly-from" referenced hovering display when all other basic instruments are "fly-to" referenced) are so serious for the average pilot that adoption of a hovering indicator should be deferred until (a) an easily used hovering indicator display concept compatible with present instrumentation is developed, or (b) the reference sense of all Army aircraft instrumentation is changed to conform with natural response tendencies.

13 Dec 1963

Introduction

1. The first section of the report contains conclusions based on human factors considerations relative to component design, system operation, and Army aviation mission requirements.

2. The second part of the report presents a detailed listing of the human factors discrepancies of each system. For convenience, discrepancies are classified as (a) component discrepancies if they relate to only one piece of hardware, (b) interaction discrepancies if they involve relationship between two or more components, either within the doppler system, or between the doppler system and other display-control systems, (c) system discrepancies if they relate to a system as a whole or to the capability of a system to meet Army aviation mission requirements, and (d) location discrepancies if they relate to the specific location of system components in AO-1 Mohawk test aircraft.

2.1 Location discrepancies should not be used as a basis for accepting or rejecting a particular doppler navigation system because the location of system components in test aircraft would not necessarily reflect the location of components in operational aircraft. However, there will be few alternatives in locating the components because of the obvious space limitations in the aircraft cockpits in which the systems will eventually be placed. In making decisions relative to component location in operational aircraft, careful consideration should be given to location discrepancies mentioned in this report.

2.2 The helicopter hovering indicators were not physically examined. All criticisms and discussions relative to the hovering indicators are based on examination of large scale photographs and discussion with test personnel.

2.3 The Manufacturer D pictorial display is treated separately because the same display component will be used regardless of the doppler system adopted. Only the later version of the pictorial display (the model featuring the automatic bug reset) was evaluated in detail.

3. The final section of the report contains a discussion of some of the human factors aspects of the doppler navigation systems with particular emphasis on Army aviation mission requirements and display-control response compatibility.

13 Dec 1963

AD-A031 912 ARMY AVIATION TEST BOARD FORT RUCKER ALA F/G 17/7
MILITARY POTENTIAL TEST (COMPARATIVE EVALUATION) OF DOPPLER NAV--ETC(U)
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Detailed Considerations

1.0 System of Electronics Division, Manufacturer A

1.1 Component discrepancies

1.11 Function-mode selector

1.111 Standby and memory caution lights are excessively bright and do not appear to be adjustable.

1.112 Magnetic variation cannot accurately be inserted in fractions of a degree because fractional parts of a degree are not provided on the magnetic variation units counter.

1.113 The label "MAG VAR" should be changed to the label "VARIATION."

1.1131 Magnetic variation is a standardized term used to designate the difference between magnetic north and true north. However, this system should use the difference between magnetic north and grid north as variation. The term "variation" is recommended since the term "grid variation" is a standardized term used to designate the difference between true north and grid north.

1.114 Reflections produce some reduction in the visibility of the magnetic variation counters.

1.115 The label GRD should be changed to GROUND because GRD is not considered to be a common or well-known abbreviation.

1.116 To prevent accidental wind settings, wind speed and wind direction set switches should automatically reposition to neutral when released.

1.12 Position-counter module

1.121 Reflections produce some reduction in the visibility of the counters.

1.122 Destination counters are difficult to set because of lag and coasting between the control knobs and counter drums.

1.123 Index marks on the counters are small and difficult to see.

1.124 Four-digit counters permitting digital setting to tenths of kilometers should be provided. If changed to read in kilometers, the label "DISTANCE TRAVELED" should be changed to "PRESENT POSITION."

1.125 The use of two sets of destination insertion control knobs is undesirable.

1.126 The dual white outlines, dual "DESTINATION" labels, and control knob numbering produces confusion in the use of the destination counter controls.

1.1261 A single outline around the entire destination counter and control group should be used instead of the two separate outlines.

1.1262 A single "DESTINATION" label should be used within this outline.

1.1263 If necessary to use duplicate controls, a number "1" should be placed directly on the end of each of the blank destination one control knobs, and a number "2" placed directly on the end of each of the gray destination two control knobs.

1.127 Counter inputs should be in kilometers.

1.128 It appears that north and east counters rotate in one direction, while south and west counters rotate in the opposite direction. All counters should rotate in the same direction (that of the north and east counters) to facilitate fractional readings.

1.129 The label "DESTINATION" above the operational mode selector switch is superfluous. It should be removed, thus reducing clutter and competition with the other destination label(s).

1.13 Bearing/distance indicator (BDI).

1.131 The index mark on range is small and difficult to see.

1.132 A distinction should be made between the unit counter markings representing 1/2 unit and those representing 1 unit.

1.14 Wind/ground display

1.141 The index mark on the counter is small and difficult to see.

1.142 A distinction should be made between the unit counter markings representing 1/2 unit and those representing 1 unit.

1.143 This unit should be labeled to indicate its display functions and should clearly indicate which of these functions is being displayed.

1.2 Interaction discrepancies

1.21 Function-mode selector relative to the wind/ground display

1.211 Accidental displacement of the WIND/GRD switch on the function-mode selector could cause gross errors in interpreting the wind/ground display.

1.212 The separation of the function-mode selector from the wind/ground display makes it necessary to control wind speed and direction switches on the function-mode selector while watching the wind/ground display.

1.213 The wind/ground display should be appropriately labeled to reflect its relationship to the wind/ground switch on the function-mode selector.

1.214 Only the counter and upper index mark provide information on the wind/ground display. It would be desirable to move the display and wind set switches from the function-mode selector to the wind/ground display, placing these around the unused lateral and lower portions of the display.

1.22 Bearing/distance indicator relative to the wind/ground display

1.221 An appropriate label on the wind/ground display will

1.123 Index marks on the counters are small and difficult to see.

1.124 Four-digit counters permitting digital setting to tenths of kilometers should be provided. If changed to read in kilometers, the label "DISTANCE TRAVELED" should be changed to "PRESENT POSITION."

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1.126 The dual white outlines, dual "DESTINATION" labels, and control knob numbering produces confusion in the use of the destination counter controls.

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1.212 The separation of the function-mode selector from the wind/ground display makes it necessary to control wind speed and direction switches on the function-mode selector while watching the wind/ground display.

1.213 The wind/ground display should be appropriately labeled to reflect its relationship to the wind/ground switch on the function-mode selector.

1.214 Only the counter and upper index mark provide information on the wind/ground display. It would be desirable to move the display and wind set switches from the function-mode selector to the wind/ground display, placing these around the unused lateral and lower portions of the display.

1.22 Bearing/distance indicator relative to the wind/ground display

1.221 An appropriate label on the wind/ground display will

reduce the possibility that the display will be confused with the bearing/distance indicator.

1.23 Position counter module relative to bearing/distance indicator

1.231 It is not possible to set in a new destination in flight without introducing erroneous information on the BDI. The equipment should be designed so that BDI information to one destination is not lost while setting in coordinates of the other destination.

1.3 System discrepancies

1.31 Position-counter inputs should be in kilometers. Nautical mile inputs are not compatible with tactical maps unless measurements are manually converted.

1.32 The provision for correction of the present position counters is not compatible with Army mission requirements.

1.321 The counters must be turned off in order to correct or change them, with consequent loss of signal during the period they are off.

1.3211 If attempting to correct error after a fix, the concurrent signal loss will probably produce greater error than that being corrected.

1.3212 If operated as presently required for error correction (turning off, setting in coordinates of an anticipated fix, and starting as the fix is passed), the system will be made useless if the anticipated fix is not actually encountered (unlikely at altitude, but highly probable on the deck).

1.3213 It should be noted that it would be impractical to correct error with a moving set of counters.

1.32131 Values of two 2- to 4-digit numbers would have to be remembered at the time of fix passage, and their difference from the actual fix coordinates determined. This task would seldom be successfully accomplished during low altitude flight.

1.32132 If the task of 1.32131 could be accomplished successfully, there is no way the error determined could be accurately inserted into the moving counters without introducing additional displays and controls.

1.322 In order to provide for correction of position error in a manner compatible with Army low altitude mission requirements it appears necessary to introduce a second set of position counters.

1.3221 This second set of counters could be set to the coordinates of an anticipated fix, and the advancement signal switched to this set of counters at the moment of passing the fix. If the fix is not encountered, the first set of counters can be left running. The initial set of counters should stop (without coasting) when the signal is switched, so that in memory mode the difference between indicated and actual fix coordinates can be used tc revise wind estimates.

1.323 Although the position counters should not normally be driven by the pictorial display bug, a switch should be provided on the pictorial display making it possible to slave the counters to the slewing of the bug on the pictorial display.

1.3231 This would facilitate counter correction considerably in situations where counter and pictorial displays correspond, but are both in error. The error correction could be made directly on the source of error information without additional mental processing.

1.3232 By appropriate switch use it should be possible to make reasonably accurate corrections of the counters while they are moving. In particular, it should be possible to reduce error in situations where position counters are started even though the intended fix is not directly overflown, but is seen to the side of the flight patch.

1.34 On entering memory mode, the system locks in the wind and ground speed at the moment of switching. If in a gust at that moment (chances are high that this will be the case), the wind vector retained in memory mode will be erroneous, and at helicopter speeds

could contribute substantial error to memory mode position computations.

1.341 It would be desirable to provide integrator circuits that would insert a wind vector averaged over the preceding several minutes upon switching into memory mode.

1.342 In memory mode, it should be possible to manually change ground speed and track directly, rather than doing this indirectly by changing wind direction and velocity (i.e., ground speed and track should change wind rather than vice versa.). The information for making changes will usually be in the form of ground speed and track (actually drift), and additional manual data processing into wind vector information should not be required.

1.4 Location discrepancies

1.41 Function-mode selector

1.411 The location of the unit prohibits adequate reading ease by either pilot or copilot when their seat and shoulder harnesses are fastened. The selector switch interferes with reading OFF and STBY positions from the pilot's seat. Neither pilot nor copilot can adequately read all the digits in the magnetic variation window because of the extreme reading angle and blocking by the control knobs.

1.42 Position-counter module

1.421 RESET and RUN toggle switch labels are blocked, from the pilot's seat, by the distance traveled cranks.

1.43 Bearing/distance indicator

1.431 The range index and approximately 1/3 of the dial are blocked for the copilot by the standby attitude indicator.

13 Dec 1963

2.0 System of Manufacturer B

2.1 Component discrepancies

2.11 Function-mode selector

2.111 Reflections produce some reduction in the visibility of ground speed and drift angle information.

2.12 Position-counter module

2.121 There is a display-control reversal between wind speed and direction control knobs and the related display counters. Turning the controls clockwise results in decreasing readings on the speed and direction counters, rather than increasing readings as should be the case.

2.122 The magnetic variation display window is labeled CORRECTION. It should be relabeled VARIATION, and the "DEG." label below it eliminated.

2.123 The north-south present position and destination counters are blocked from the pilot's view as he activates the related control knobs. Because of the force required to turn the knobs, it is necessary to grasp them with the thumb and fingers. As a result, the entire hand is placed in the line of vision. A control which could be activated without grasping would resolve the problem. A comparable situation exists for the copilot when he sets the east-west counters.

2.124 There are no decimal markers on the present position or destination counter windows. The decimal part should be clearly indicated.

2.125 A reference index should be provided against the last digit present position and destination counters.

2.126 The N-S-E-W letters should be placed before (at the left) of the counters for present position, destination, and variation.

2.127 The seven "PUSH" labels should be labeled with a type size significantly smaller than the other labels. Their elimination should be considered.

2.128 The wind displays and controls should be outlined, the "DIRECTION DEG" label moved above the counter and the "DEG" part eliminated.

2.13 Bearing/distance indicator

2.131 Parallax will cause slight reading inaccuracy on the range scale.

2.132 There is excess space between the two discs in the range display.

2.133 A wheel-type of counter is preferable to the disc-type counters used. This counter is subject to excessive interpolation ambiguity that should not be accepted for displays of a low altitude navigation system.

2.134 The instrument is not adequately lighted for night operations. Shadows and reflections produce some reduction in the legibility of numbers, particularly the range counters.

2.135 The range numerals are overlapped by two pointers. There is some masking, but it is not considered serious.

2.2 Interaction discrepancies

2.21 Position counter module relative to bearing/distance indicator

2.211 It is not possible to set in a new destination in flight without introducing erroneous information on the BDI. The equipment should be designed so that BDI information to one destination is not lost while setting in coordinates of the other destination.

2.3 Systems deficiencies

2.31 The provision for correction of the present position counters is not compatible with Army mission requirements.

2.311 The counters must be turned off in order to correct or change them, with consequent loss of signal during the period they are off.

2.3111 *If* attempting to correct error after a fix, the concurrent signal loss will probably produce greater error than that being corrected.

2.3112 If operated as presently required for error correction (turning off, setting in coordinates of an anticipated fix, and starting as the fix is passed), the system will be made useless if the anticipated fix is not actually encountered (unlikely at altitude, but highly probable on the deck).

2.3113 It should be noted that it would be impractical to correct error with a moving set of counters.

2.31131 Values of two 2- to 4-digit numbers would have to be remembered at the time of fix passage, and their difference from the actual fix coordinates determined. This task would seldom be successfully accomplished during low altitude flight.

2.31132 If the task of 2.31131 could be accomplished successfully, there is no way the error determined could be accurately inserted into the moving counters without introducing additional displays and controls.

2.312 In order to provide for correction of position error in a manner compatible with Army low altitude mission requirements it appears necessary to introduce a second set of position counters.

2.3121 This second set of counters could be set to the coordinates of an anticipated fix, and the advancement signal switched to this set of counters at the moment of passing the fix. If the fix is not encountered, the first set of counters can be left running. The initial set of counters should stop (without coasting) when the signal is switched, so that in memory mode the difference between indicated and actual fix coordinates can be used to revise wind estimates.

2.313 Although the position counters should not normally be driven by the pictorial display bug, a switch should be provided on the pictorial display making it possible to slave the counters to the slewing of the bug on the pictorial display.

2.3131 This would facilitate counter correction considerably in situations where counter and pictorial displays correspond, but are both in error. The error correction could be made directly on the source of error information without additional mental processing.

2.3132 By appropriate switch use it should be possible to make reasonably accurate corrections of the counters while they are

moving. In particular, it should be possible to reduce error in situations where position counters are started even though the intended fix is not directly overflown, but is seen to the side of the flight path.

2.32 On entering memory mode, the system locks in the wind and ground speed at the moment of switching. If in a gust at that moment (chances are high that this will be the case), the wind vector retained in memory mode will be erroneous, and at helicopter speeds could contribute substantial error to memory mode position computations.

2.321 It would be desirable to provide integrator circuits that would insert a wind vector averaged over the preceding several minutes upon switching into memory mode.

2.4 Location discrepancies

2.41 Function-mode selector

2.411 The ground speed/drift angle display is partially blocked from the copilot's view as he activates the controls.

2.42 Position-counter module

2.421 North destination and present position counters are blocked from the view of the pilot as he activates the control knobs. East counters are blocked to the copilot as he activates the controls.

2.43 Bearing/distance indicator

2.431 The index mark on the range scale is difficult to see from the copilot's seat.

13 Dec 1963

3.0 System of Manufacturer C

3.1 Component discrepancies

3.11 Function-mode selector and position-counter module

3.111 Reflections produce some reduction in the visibility of the counters.

3.112 The fraction marks on the magnetic variation units drum are not clearly differentiated as to value.

3.113 No index mark is provided for setting or reading fractions of degrees of magnetic variation. An additional counter wheel should be provided for this purpose.

3.114 Manually setting wind requires that three knobs be manipulated.

3.115 Grasping the knobs for setting present position and destination results in some blockage of counters. A control permitting operation without grasping would resolve the problem.

3.116 The trademark should be removed.

3.12 Bearing/distance indicator

3.121 Pointer destination location bars, and azimuth and range reference lines block part of the counter and mode windows. Reduction in the number of radial reference lines should be considered.

3.122 The number "5" which appears four times on the outer range circle is unnecessary, and should be eliminated.

3.123 The short, medium, and long labels, indicating 5, 50, or 500 mile range modes should be relabeled with the numbers 5, 50, and 500 to minimize interpretation errors.

3.124 Parallax is evident between the track pointer and the direction scale, and between the X-Y axes and the concentric circles. The parallax can cause minor reading errors.

3.125 When the panel indicator is on red light, white incandescent illumination is reflected around the edges of the inside display card. This should be corrected.

3.126 The ground speed counter does not contribute particularly useful information toward mission accomplishment. It should normally indicate range to destination, with a switch provided for indicating ground speed when this is required. With this counter range reference circles could be reduced to full and one-half scale rings since quantitative values would be obtained from the counter.

3.1261 The pictorial display used seems prone to range errors, and a redundant digital presentation of range would minimize these errors while avoiding interpolation requirements.

3.127 The scale change switching points should be accomplished automatically or manually at or slightly under the mid-scale point. Requirements for use near the center should be avoided by providing a standard set of scales with maximum range 5, 10, 25, 50, 100, 250, and 500. The capability to change scales manually in either direction should be provided.

3.2 Interaction discrepancies

3.21 BDI relative to position-counter module

3.211 To manually set wind requires that the operator activate one switch on the BDI and three knobs on the position-counter module. Interpolation is required when setting wind speed. It is also necessary to consider the mode of the range scale when setting wind.

3.22 Position counter module relative to bearing/distance indicator

3.221 It is not possible to set in a new destination in flight without introducing erroneous information on the BDI. The equipment should be designed so that BDI information to one destination is not lost while setting in coordinates of the other destination.

3.3 Systems deficiencies

3.31 The provision for correction of the present position counters is not compatible with Army mission requirements.

3. 311 The counters must be turned off in order to correct or change them, with consequent loss of signal during the period they are off.

3. 3111 If attempting to correct error after a fix, the concurrent signal loss will probably produce greater error than that being corrected.

3. 3112 If operated as presently required for error correction (turning off, setting in coordinates of an anticipated fix, and starting as the fix is passed), the system will be made useless if the anticipated fix is not actually encountered (unlikely at altitude, but highly probable on the deck).

3.3113 It should be noted that it would be impractical to correct error with a moving set of counters.

3. 31131 Values of two 2- to 4-digit numbers would have to be remembered at the time of fix passage, and their difference from the actual fix coordinates determined. This task would seldom be successfully accomplished during low altitude flight.

3. 31132 If the task of 3. 31131 could be accomplished successfully, there is no way the error determined could be accurately inserted into the moving counters without introducing additional displays and controls.

3. 312 In order to provide for correction of position error in a manner compatible with Army low altitude mission requirements it appears necessary to introduce a second set of position counters.

3. 3121 This second set of counters could be set to the coordinates of an anticipated fix, and the advancement signal switched to this set of counters at the moment of passing the fix. If the fix is not encountered, the first set of counters can be left running. The initial set of counters should stop (without coasting) when the signal is switched, so that in memory mode the difference between indicated and actual fix coordinates can be used to revise wind estimates.

3. 313 Although the position counters should not normally be driven by the pictorial display bug, a switch should be provided on the pictorial display making it possible to slave the counters to the slewing of the bug on the pictorial display.

3.3131 This would facilitate counter correction considerably in situations where counter and pictorial displays correspond, but are both in error. The error correction could be made directly on the source of error information without additional mental processing.

3.3132 By appropriate switch use it should be possible to make reasonably accurate corrections of the counters while they are moving. In particular, it should be possible to reduce error in situations where position counters are started even though the intended fix is not directly overflown, but is seen to the side of the flight path..

3.32 There is no provision for permanent retention of bearing and distance to base.

3.33 There is no provision for the system to manually be placed in memory-mode operation by the crew. Malfunctions that are of degree (calibration malfunctions) seem likely, but the crew is incapable of utilizing the remaining information processing capability of the system if the system does not itself switch into memory mode.

3.34 On entering memory mode, the system locks in the wind and ground speed at the moment of switching. If in a gust at that moment (chances are high that this will be the case), the wind vector retained in memory mode will be erroneous, and at helicopter speeds could contribute substantial error to memory mode position computations.

3.341 It would be desirable to provide integrator circuits that would insert a wind vector averaged over the preceding several minutes upon switching into memory mode.

3.342 In memory mode, it should be possible to manually change ground speed and track directly, rather than doing this indirectly by changing wind direction and velocity (i.e., ground speed and track should change wind rather than vice versa.). The information for making changes will usually be in the form of ground speed and track (actually drift), and additional manual data processing into wind vector information should not be required. Therefore, a capability for setting drift angle should be provided.

3.4 Location deficiencies

3.41 Function-mode selector and position-counter module

3.411 Approximately 1/2 of the magnetic variation window is blocked to the copilot as he activates the control knobs.

3.42 Bearing/distance indicator

3.421 There appear to be no serious location deficiencies.

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4.0 The pictorial display of Manfacturer D

4.1 Component discrepancies

4.11 The rheostat controlling light intensity does not produce even changes in light intensity. A desired level of illumination is difficult to obtain.

4.12 Intensity of Illumination varies over the display to an undesirable degree.

4.13 The red "bug" is not visible under red lighting.

4.14 Reflections from internal lighting considerably reduce map visibility in night use when viewed from an appreciable angle.

4.15 Ultraviolet lighting in combination with maps sprayed with ultraviolet-luminescent phosphors might be used to alleviate some of the lighting difficulties.

4.16 The display may require an excessive degree of attention at map change points.

4.2 Interaction discrepancies

4.21 It would be desirable to provide a switch permitting correction of present position counters by slewing of the pictorial display bug.

4.3 System discrepancies

4.31 Proper use of the pictorial display on long routes will require lengthy map preparation, although once prepared, selection for a specific mission will be relatively direct.

4.32 The concept of map programming is extremely limited in mission flexibility.

4.4 Location discrepancies

4.41 The display cannot be used by the pilot when he is alone because of the display's location.

5.0 Helicopter Hovering Indicators

5.1 Manufacturer A

5.11 Component discrepancies

5.111 Discrimination of small changes with necessary accuracy appears doubtful with the present scaling. Higher ratio logarithmic scales providing increased discrimination near zero on all scales would be desirable.

5.112 The fine scale divisions near zero add clutter which should increase the difficulty of detecting changes requiring control responses.

5.113 The display employs two different frames of reference. The vertical velocity indicator uses the "fly-from" reference sense. The lateral and track velocity indicators use the "fly-to" reference sense. This violates a cardinal design principle of not mixing these reference systems.

5.114 A zero vertical velocity reference index that is considerably more prominent than nearby scale markings should be provided.

5.115 Replacement of the drift velocity and heading velocity indicator bars with a single circular cursor at their intersection should be considered. Design-wise, this should involve replacing the visible bars with nonvisible wires, and then providing a cursor at their intersection which would be the only visible aspect.

5.116 The curved portions of the 5- and 15-knot velocity reference lines should be replaced by curved velocity reference lines aligned with the 10- and 20-knot velocity reference marks.

5.117 An adequate "fail-safe" warning indicator should be provided. The label OFF is not considered satisfactory as a warning device.

5.12 Interaction discrepancies

5.121 The combined use of "fly-to" and "fly-from" reference senses on the hovering indicator requires that different display/control responses be made at the same time with the two hands.

5.122 The hovering indicator and the attitude indicator present directly opposed indications as the nose is pitched down to increase forward velocity from a hover. The close coordination required between the two indicators during hover and transition makes such opposing indications particularly serious.

5.13 System discrepancies

5.131 Analysis of Army information requirements for the IFR hovering situation indicates that absolute altitude information is critical for a successful accomplishment of this task. This information is so critical that it needs to be incorporated into the hovering display indicator. If it is provided, the necessity for providing an additional rate of climb display on the hovering indicator is doubtful.

5.2 Manufacturer C

5.21 Component discrepancies

5.211 The labels THOUSAND and HUNDRED indicating the mode of the vertical velocity indicator are not considered adequate status indicators. Part of the inadequacy is associated with the location of the label in such a position that, when the instrument is viewed from an extreme angle, the label is not readily visible. A misinterpretation of the mode of the vertical velocity indicator would produce a 10-factor error and could be extremely critical.

5.2111 The sudden shift between scales is undesirable.

5.212 There is a definite possibility that the heading and drift velocity bars will block the vertical velocity scale and index and interfere with accurate reading of vertical velocity.

5.213 A zero vertical velocity reference index that is considerable more prominent than nearby scale markings should be provided.

5.214 Replacement of the drift velocity and heading velocity indicator bars with a single circular cursor at their intersection should be considered. Design wise, this should involve replacing the visible bars with nonvisible wires, and then providing a cursor at their intersection which would be the only visible aspect.

5.215 On the heading velocity and drift velocity scales, the range of the scale and the value of the scale divisions should be indicated. If the range of the scale is to be 10K, the extreme markings of each scale should be labeled 10. If the range of the scales is to be 30K, the entire scale should be divided into units of 5K, with the 10K intervals labeled 10, 20, and 30.

5.2151 If a scale range of 30 knots is used discrimination of small change with necessary accuracy appears doubtful. In this case logarithmic scales providing increased resolution near zero would be desirable.

5.216 An adequate "fail-safe" warning indicator should be provided. The label OFF is not considered satisfactory as a warning device.

5.22 Interaction discrepancies

5.221 The use of a display with all "fly-from" reference sense will result in a completely mixed instrument panel. Although the natural display concept used is considered best for accomplishing hovering performance from the standpoint of both reference sense and display-control response compatibility, it can be expected to result in a significant increase in reversal tendencies in the use of other cockpit instruments which are based on an unnatural display concept.

5.2211 A resolution of this design conflict is not possible on an interim basis. Its resolution appears to require a reversal in the philosophy of Army aircraft instrumentation from unnatural to natural reference sense.

5.23 System discrepancies

5.231 Analysis of Army information requirements for the IFR hovering situation indicates that absolute altitude information is critical for a successful accomplishment of this task. This information is so critical that it needs to be incorporated into the hovering display indicator. If it is provided, the necessity for providing an additional rate of climb display on the hovering indicator is doubtful.

Discussion

For a navigation system to be "optimal" for tactical use by Army aviation, it should have the following characteristics: (a) require a minimum of preflight preparation, (b) provide continuous information in the operational terrain reference systems on present position relative to chosen destination, (c) be adaptable to manual inputs, and (d) provide for manual in-flight corrections without loss of computer information.

All of the systems under consideration fail to meet the last requirement (d) which should be considered critical. That is, no system can be suitably updated or manually corrected without the loss of computer information. For that reason none of the systems is acceptable from a human factors standpoint.

Any navigation system to be adopted for widespread tactical use in Army aviation should be functionally designed to meet the unique demands of combat conditions. The requirement for quick and accurate in-flight computer corrections based on human observations of error is one that should be met in <u>any</u> tactical navigation system used by the Army.

In the evaluated systems it is necessary for the pilot to (1) notice the discrepancy, (2) determine the amount, (3) stop the computer, (4) reset the "present position" or "distance traveled" counters, (5) make a "go-around" over a known check point, (or else accomplish 3 and 4 before passing over the check point.) and (6) reactivate the computer as the plane passes over the point. Provisions should be made such that: (1) the pilot notices a discrepancy between computer readout of position and actual position, (2) he determines the amount of discrepancy, and (3) feeds it into the computer without losing range or other computer information or making a "go-around." In other words, the pilot should be able to "correct" the computer without unnecessary calculation, without losing computer information, and without losing time or increasing the risk of exposing himself to hostile fire.

With the systems as considered, the only obvious way to correct without a "go-around" is to add or subtract the discrepancy from the "destination" coordinates so that distance to destination information will be accurate. This method probably will prove impractical because of the accumulation of corrections necessary over a long flight. These accumulations could easily tax the memory of the pilot.

This basic system deficiency does not preclude the fact that all of the doppler systems being examined provide information which can reduce the complexity and increase the accuracy and efficiency of navigation. All three provide the pilot with position information in a readily usable form. But, the accuracy of the information could be significantly increased by providing a manual updating capability.

The display concept of the Manufacturer C bearing-distance indicator is considered superior to the other types of indicators due to the "pictorial" image of aircraft position relative to destination, although it would be desirable to provide the option of switching it into an aircraft referenced display which would give an "align up" indication for tracking toward destination.

The Manufacturer C position-counter module does not provide a capability for permanent retention of information on bearing and distance to base. The Manufacturer B system provides this capability, and it is regarded as an advantage. Since the Manufacturer A system "base" is zero on the counter, this feature is of no value since it is unlikely that the system would be used tactically with zero as base coordinates. Actual base coordinates would usually be used.

The pictorial display, which is common to all three doppler systems, will be of marginal value in a tactical environment because of planning and in-flight attention requirements. However, the pictorial display will be of value whenever the mission, or the attention-demanding portions of it, can be flown on one chart. The lighting of the present display is uneven and tends to produce reflections and glare. The present location of the display makes it difficult for the pilot to use if he is alone because he cannot change the maps. Once charts are prepared, proper use of the pictorial display will considerably reduce the track-keeping and information-processing requirements currently placed on the operator during portions of long tactical flights. In most cases, it will give a reasonably accurate pictorial presentation of present position. The use of ultraviolet illumination and maps sprayed with ultraviolet luminescent phosphors might avoid some of the illumination problems of the pictorial display.

On the Manufacturer A helicopter hovering indicator, forward motion of the aircraft causes the heading velocity bar to move down, and right drift causes the drift velocity bar to move to the left. On the Manufacturer C indicator, forward motion causes the heading

velocity bar to move up, and right drift causes the drift velocity bar to move right. On both Manufacturer A and Manufacturer C indicators, upward motion causes the vertical velocity indicator to move up.

The Manufacturer A helicopter hovering indicator incorporates both "fly-to" and "fly-from" reference sense. From the human factors point of view, the use of both reference senses in the same instrument is very undesirable.

In addition to the mixed reference sense of the Manufacturer A display, the display-control response relationships are different for the two hands. The collective in the left hand is used in a "control from" movement with respect to the display deflection, while the cyclic in the right hand is used in a "control to" movement with respect to the display deflection. It should be noted that reference sense and display-response control compatibility conflicts are actually separate considerations, but they correspond due to systematic relations established between control movement and VFR reference sense.

On transition from the Manufacturer A hover display to the attitude display a reversal of indication occurs. As shown in Figure 1, the moving part on the Manufacturer A hovering display goes below the reference mark as the nose is pitched and forward velocity increases, but on shifting to the attitude indicator the moving part is above the reference mark. Although uncertain, it appears likely that the average pilot will experience difficulty with this transition.

The Manufacturer C display on which all hover indicator responses are the "fly-from" type, avoids the problems of mixed reference, mixed response, and indication reversal on transition to the attitude indicator. However, this results in a fully mixed panel, for which serious consequences can be expected. It does follow the established trend of using "fly-from" displays when the natural response tendencies are too strong to overcome--for example, the rate of climb indicator and the turn indicator.

The above conflicts relate to one of the fundamental problems of aviation psychology, and no satisfactory immediate solution is attainable for the conflicts related to the hover displays. The Manufacturer C hovering indicator is considered superior to the Manufacturer A indicator for achievement of satisfactory instrument hovering performance. However, its adoption will result in a fully mixed

panel, with the hover indicator used in one reference and control sense and the attitude indicator in the reversed reference and control sense. This fully mixed panel may be expected to result in a significant increase in serious accidents associated with control reversals due to this mix.

The increasing requirement in Army aviation for unfailingly correct fast response to displays dictates that the Army must eventually convert to a natural reference sense instrument panel. The desire to utilize lower aptitude personnel to fill pilot seats and to reduce training and proficiency time also dictates a change to a natural presentation. Army aviation display requirements are approaching a critical point in this regard that is far less critical in the other services who still typically operate at forgiving altitudes. The only apparent solution at present time is a shift to a natural presentation instrument panel.

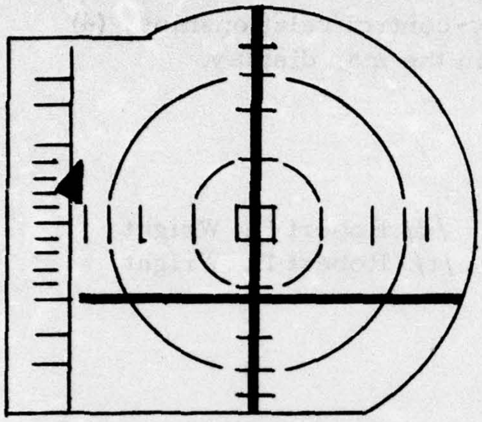
However, the magnitude of such a change cannot be disregarded. It presents a logistics problem of such proportions that it could only be undertaken after study and decisions at the highest level. Human factors studies with typical personnel on natural display systems are required to provide the confirming data needed for such a decision.

Most of the other human engineering discrepancies of each system are not "critical" in the sense that they would typically lead to a mission failure. Most discrepancies are of a type that, compared with a properly human engineered system for Army aviation use, will require more time from the user, will have a higher probability of error associated with their use, and will require greater mental effort on the part of the user. The specific discrepancies are listed for each system in the "Detailed Consideration" section. Although most are relatively minor discrepancies, they should tend to interact in an accumulative fashion so that, for any one system, they should result in some degradation of mission capability. Among the specific discrepancies common to all the systems are: (1) reading difficulty caused by poor index marks, and reflections and glare from the glass over the counters and dials, (2) partial blocking of displays and controls caused primarily by placement

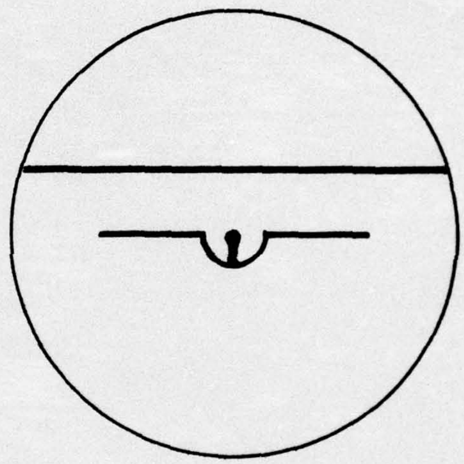
of the units and the arrangement of control knobs on the units, (3) a variety of incorrect labels and display-control relationships, (4) generally poor lighting, particularly in the map display.

/s/ Robert H. Wright
/t/ Robert H. Wright

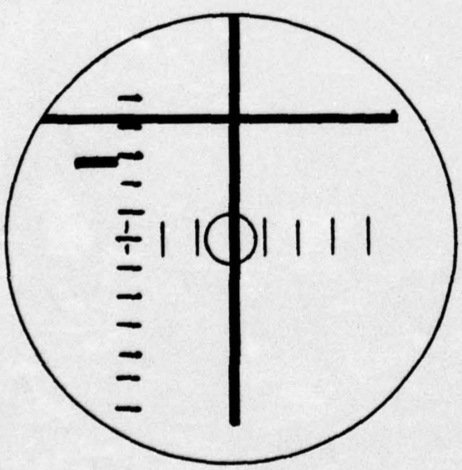
T. Gary Waller
Research Associate



Manufacturer A Hover
Indicator



Attitude Indicator



Manufacturer B Hover
Indicator

Fig. 1. Approximate configuration of hover and attitude indicators during transition from hover to forward flight.

APPENDIX O

LIST OF REFERENCES

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3. Letter, ATBG-AVAB, US Army Aviation Board, 26 June 1962, subject: "Doppler Navigation Principles, Concepts, and Problems related to Doppler Navigational Systems for the US Army."

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5. US Army Electronics and Development Laboratories Technical Requirement, SCL 5953, subject: "Lightweight Airborne Doppler Navigator," dated 10 May 1963.

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22. FAA Technical Standard Order (TSO) C68 Part 514, subject: "Airborne Automatic Dead Reckoning Computer Equipment Utilizing Aircraft Heading and Doppler Obtained Ground Speed and Drift Angle Data (For Air Carrier Aircraft)."

23. Final Report, Evaluation of Doppler Techniques in Air Traffic Control, Task No. 116-7-1T, prepared by A. W. Grimes, Federal Aviation Agency, Aviation Research and Development Service, Atlantic City, New Jersey, February 1961.

24. Paper by Robert H. Mayer, "Doppler Navigation for Commercial Aircraft in the Domestic Environment," Federal Aviation Agency, Atlantic City, New Jersey.

25. Position Paper for VII Com Division, Agenda Item No. 11-5, subject: "Possibility of Using the Doppler Navigation System as a Short Distance Area Coverage, NAVAID."

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27. Letter, Ref: CPD/DEF/630380, Manufacturer C, 17 December 1963, with two inclosures.

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APPENDIX P

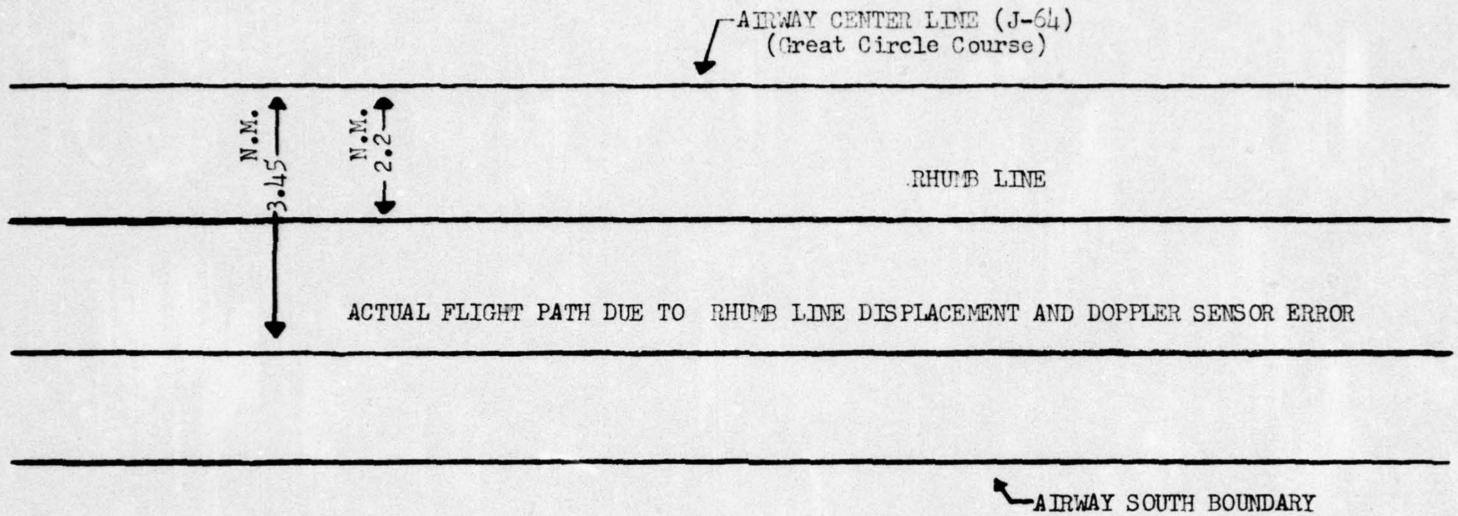
The Employment of a Doppler Navigation System on Federal Airways.

The United States recognizes that because of inaccessible terrain to locate ground NAVAID's to provide total United States coverage, Doppler navigation systems may be the practical means of navigation. The following is quoted from reference 24 which states advantages and disadvantages when employing a Doppler Navigation System for civil airway use:

"In using the Doppler Navigator, or any rhumb line system, one must consider the mid-course displacement between the rhumb line course (Doppler) and the great circle Victor airways route. This mid-course displacement places the rhumb line course to one side of the centerline of the airway. The mid-course displacement is maximum when flying at a constant latitude and zero when flying a meridian. To get a feel for the relative importance of this displacement let us consider the mid-course displacement between Yardley (ARD) and Pittsburg (PIT) Pennsylvania, along the high altitude jet route J64, a distance of 245 nautical miles. The mid-course displacement is most simply determined graphically by laying the great circle and rhumb lines on a lambert conformal chart and scaling the mid-course deviation. It is thus seen that the rhumb line is 2.2 nautical miles south of the great circle J64 centerline. Now let us consider a situation where the 1% of distance traveled cross course system error, previously discussed, lies to the south of the rhumb line and is therefore added to the rhumb line displacement. It is then seen that the mid-course displacement will be 3.45 nautical miles south of the airway centerline. Figure 2 shows this relationship. It is noted, however, that the cross course error at the termination of the airway is only affected by the system error and in the case sighted will be 2.45 nautical miles and is well within the airway width. Another cross course error results from the use of average variation between way points. A cross error of one nautical mile may result by averaging a two degree variation differential.

"The along course accuracy of the Doppler System is affected by the same mechanization errors as the cross course accuracy, except that the heading errors have a negligible effect on the along course accuracy. The standard deviation along course errors observed by one airline ... when fix corrections, if any, were removed from the data, were less than 1 percent of the distance traveled. A round figure of 1 percent distance traveled along course error suggests itself for this application.

"Although no conclusions should be drawn without verification by experimentation, the above observations indicate that the Doppler System may be utilized to fly the domestic system airways. Furthermore, the Doppler is unaffected by VOR scalloping, padding, etc. Because of the along course, and cross course distances type of presentation, the Doppler lends itself well to area navigation that may be required by weather or ATC requirements. The Doppler has the disadvantage in this application that the terminal point, because of the distance varying error, may not be as accurately located as the VOR flag alarm, thus a combination procedure is suggested." See figure 34.



MID COURSE DISPLACEMENT
Rhumb Line From Great Circle

Figure 40.

APPENDIX Q

COMBAT DEVELOPMENT OBJECTIVES GUIDE

PARAGRAPH 533 c (5)

(Classified; presented under separate cover.)

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AD______________________ Accession No. ______________________
US Army Aviation Test Board, Ft. Rucker, Alabama. Military Potential Test (Comparative Evaluation) of Doppler Navigation Systems. Final report, 7 January 1964. USATECOM Project No. 4-3-3600-( )-G. 233 pp., 43 illus. Unclassified report. Five Doppler navigation systems (Dopplers A(FW), A(RW), B, C(FW), and C(RW)) were tested to develop test data for use as a basis for recommending the most suitable Doppler navigation system(s) for Army use. It was concluded that the Doppler navigation systems of Manufacturers A and C are the most suitable of all the systems tested for Army use in both fixed- and rotary-wing aircraft, and that the pictorial navigation display board furnished with Manufacturer C's system represents the most advanced state of the art and should be considered the most suitable for Army use. It was recommended that the Doppler navigation systems of Manufacturers A and C be considered suitable for Army use in both fixed- and rotary-wing aircraft; that the deficiencies and shortcomings listed in paragraph C, part II of the report, and appendix L, part III of the report, and the discrepancies enumerated in appendix N, part III of the report, be corrected as technically and economically feasible and a confirmatory test be conducted on production models of the selected system; and that an improved compass system and associated calibration equipment for field use, compatible with the Doppler system, be provided for Army use.

AD______________________ Accession No. ______________________
US Army Aviation Test Board, Ft. Rucker, Alabama. Military Potential Test (Comparative Evaluation) of Doppler Navigation Systems. Final report, 7 January 1964. USATECOM Project No. 4-3-3600-( )-G. 233 pp., 43 illus. Unclassified report. Five Doppler navigation systems (Dopplers A(FW), A(RW), B, C(FW), and C(RW)) were tested to develop test data for use as a basis for recommending the most suitable Doppler navigation system(s) for Army use. It was concluded that the Doppler navigation systems of Manufacturers A and C are the most suitable of all the systems tested for Army use in both fixed- and rotary-wing aircraft, and that the pictorial navigation display board furnished with Manufacturer C's system represents the most advanced state of the art and should be considered the most suitable for Army use. It was recommended that the Doppler navigation systems of Manufacturers A and C be considered suitable for Army use in both fixed- and rotary-wing aircraft; that the deficiencies and shortcomings listed in paragraph C, part II of the report, and appendix L, part III of the report, and the discrepancies enumerated in appendix N, part III of the report, be corrected as technically and economically feasible and a confirmatory test be conducted on production models of the selected system; and that an improved compass system and associated calibration equipment for field use, compatible with the Doppler system, be provided for Army use.